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MINUTES AND PROCEEDINGS
of the Thirtieth meeting of the
ARMED FORCES NRC VISION COMMITTEE
April 4-5, 1952

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BY *A.P. Stewart* DATE *June 25, 1974*

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of the Thirtieth meeting of the
ARMED FORCES NRC VISION COMMITTEE

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Dr. R. H. Waters
Dunlap, Morris & Associates, Inc.

VISION COMMITTEE SECRETARIAT

Dr. H. Richard Blackwell
Dr. John H. Taylor
Mrs. Patricia F. Brown

Friday, April 4

1. The Chairman called for corrections or additions to the Minutes of the 29th meeting. There were no corrections or additions.
2. Dr. H. Richard Blackwell presented a report for the Working Group on Night Vision Testing. A Summary of the report is contained in the Proceedings. 17
3. Dr. S. D. S. Spragg presented a paper entitled "Performance on the Orthorater at Reduced Illumination Levels". The text of the report is contained in the Proceedings 19
4. Dr. H. W. Rose presented a paper entitled "A Projector for Night Vision Training of Pilots". The text of the report is contained in the Proceedings. . . 21
5. Dr. Ingeborg Schmidt presented a paper entitled "Rotator and Illuminator of Plates for Testing Color Vision". A summary of the report is contained in the Proceedings 26
6. Dr. J. M. Vanderplas presented a paper entitled "The Effect of Viewing Angle and Parallax Upon Accuracy of Reading Quantitative Scales". The text of the report is contained in the Proceedings. 28
7. Dr. S. Gerathewohl presented a paper entitled "Eye Movements in Radar Observation". The text of the report is contained in the Proceedings 33
8. Dr. J. M. Vanderplas presented Lt. Col. Walter F. Grether's paper entitled "A Discussion of Problems Related to Cathode Ray Tube Size and Other Characteristics in Radar-Scope Displays". The text of the report is contained in the Proceedings. 37
9. Mr. F. C. Breckenridge presented a paper entitled "Report on the Work of the International Commission on Illumination in Standardizing Color Specifications for Light Signals". The text of the report is contained in the Proceedings . . . 41
10. Dr. Deane B. Judd presented a paper entitled "Report on the Air Force Problem of Standard Color Filters for Electronics Equipment". The text of the report is contained in the Proceedings. 54
11. THE VISION COMMITTEE APPROVED DR. JUDD'S REPORT ON STANDARD COLOR FILTERS FOR USE IN ELECTRONICS EQUIPMENT.
12. The Desirability of Adopting the Nit as a Unit of Luminance was discussed. A Summary of the discussion may be found in the Proceedings 64
13. Dr. Rose submitted to the Vision Committee two conversion charts for a number of units of luminance, copies of which are contained in the Proceedings. . . 65
14. Dr. Alphonse Chapanis presented a paper entitled "The Apparent Length of a Line as a Function of its Orientation". The text of the report is contained in the Proceedings 67
15. Dr. W. J. Crozier presented a paper entitled "On the Parafoveal Dark Adaptation Contour". 75

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16. Dr. H. W. Rose presented a paper entitled "Visual Acuity at High Angular Speeds". An Abstract of the report is contained in the Proceedings. 77
17. Lt. Col. Elwin Marg presented a paper entitled "Flashes of Clear Vision and Negative Accommodation with Reference to the Bates Method of Visual Training". The text of the report is contained in the Proceedings 81

Saturday, April 5

18. Dr. Clement R. Brown announced the completion of a Bibliography of Visibility. A Summary of the announcement is contained in the Proceedings. 99
19. Dr. S. Q. Duntley presented a paper entitled "The Inherent Contrast of Submerged Objects". A text of the paper is contained in the Proceedings 100
20. Dr. E. O. Hulburt presented a paper entitled "Measurements and Estimates of Sky Brightness at Various Altitudes". A text of the report is contained in the Proceedings 104
21. Dr. S. Q. Duntley presented a report of the working group on visibility at high altitudes. A summary of the report is contained in the Proceedings 120
22. THE VISION COMMITTEE APPROVED THE REPORT OF THE WORKING GROUP ON VISIBILITY AT HIGH ALTITUDES.
23. Dr. R. Tousey presented a paper entitled "Visibility of Stars in the Twilight Sky". The text of the report is contained in the Proceedings. 121
24. Dr. Rolland H. Waters presented a paper entitled "Proposed Field Tests of the Tiffany Visibility Forecasting Nomographs". The text of the report is contained in the Proceedings 133
25. Dr. H. Richard Blackwell presented a report on the NRC Committee on Highway Safety Research. A summary of the report is contained in the Proceedings 138
26. Mr. L. P. Harrison announced the instigation of a project concerning visibility factors in aircraft landing safety. A description of the project is contained in the Proceedings 139
27. Col. Victor A. Byrnes presented a report of the meeting of the Executive Council, a summary of which is contained in the Proceedings. 147
28. THE NEXT MEETING OF THE VISION COMMITTEE WILL BE HELD NOVEMBER 21-22 AT THE AERO MEDICAL LABORATORY, WRIGHT-PATTERSON AIR FORCE BASE.
29. Abstracts 148

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SUMMARY OF THE REPORT OF THE WORKING GROUP
ON NIGHT VISION TESTING

H. Richard Blackwell

A working group has been set up to advise the Adjutant General's Office, Department of the Army, in connection with a research and development program concerned with night vision testing. The working group consists of Dr. E. Parker Johnson, Chairman; Dr. Louise Sloan Rowland; Dr. Austin H. Riesen, and Dr. H. Richard Blackwell. (The report was given by Dr. Blackwell in the absence of the chairman of the working group.)

The Army interest in night vision testing is the result of the extensive occurrence of night operations in the Korean war. Field commanders feel a great need for a means of selecting combat personnel having optimal ability to see at night. It is believed that more is required than an identification of the pathologically night blind. Every effort should be made to select those with better than average night vision capacity.

Personnel of the Adjutant General's Office are well aware of the discouraging results which have been obtained in the past with night vision testing. On the other hand, they are very much impressed with the operational need for selection with respect to night vision capacity. The problem appears to be of sufficient importance so that another attempt should be made to devise a practical night vision test.

Because of the great inherent difficulty of administering tests of peripheral sensitivity at low luminances, the Adjutant General's Office has been very much attracted by the possibility of testing visual capacity at mesopic levels rather than at scotopic levels. There is every reason to believe that mesopic testing will have greater reliability than scotopic testing. There is naturally the question of the validity of mesopic testing for application to night vision performance. It may be pointed out that the question of validity is very much present also in connection with the conventional tests of scotopic visual capacity. There are a number of possible scotopic visual capacities which can be measured, and the history of night vision testing makes it clear that the various scotopic capacities have low inter-correlations. Thus it is entirely clear that there is no such thing as a "night vision capacity."

In view of the fact that the problem of validity looms large in all possible tests of night vision capacity, personnel of the Adjutant General's Office have wondered whether there was any basis for possible validity of a mesopic test. A possible basis for validity of a mesopic test may be stated as follows: The pattern of neural impulses reaching the cortex from the peripheral retina is a diffuse spatial pattern, owing to the large number of diffuse connections in the peripheral visual pathways, beginning at the retina, and extending to the cortex. It is conceivable that the crucial aspect of night vision capacity is the extent to which effective interpretation is made of the diffuse pattern of neural impulses. Such a postulation could well account for the well-documented fact that night vision capacity is subject to enormous learning effects. Recent experimental results obtained in the speaker's laboratory have indicated clearly that the foveal retina operates principally through diffuse connections at low luminance levels. The evidence comes from the spatial extent of summative effects at low luminance. If this is indeed the case, it is conceivable that the essential aspect of night vision capacity may be tested by testing foveal visual capacity at low luminance levels.

Because of this rationale for the use of a mesopic test, and because the Adjutant General's Office feels that any test having any appreciable validity would be of practical significance to the Army, members of the working group feel that development of a test of mesopic ability for night vision testing is a worthwhile venture. Members of the working group have met with personnel of the Adjutant General's Office and discussed in detail the

experimental program which the Adjutant General's Office plans to undertake. The first phase of the program involves developing a convenient test of mesopic visual capacity. It was decided that the Armed Forces Vision Tester should be modified to use for mesopic testing. The acuity tests based on letter test objects will be among those employed. Provision will be made to reduce the luminance level to at least three mesopic levels. Procedures will be incorporated both for stabilization of luminance level and for easy photometric calibration. It is essential that good control be exercised over luminance levels in this use of the vision tester since visual capacities vary markedly as a function of luminance level at low luminances. It is expected that the modified vision tester will be available for use by July 15.

The next phase of the Adjutant General's Office program involves determining the adaptation times for use in administering the mesopic tests. The intent is to ascertain the shortest possible time of dark adaptation which will yield reliable measures of mesopic visual capacity. On theoretical grounds, one would suppose that it would be necessary to continue dark adaptation to the terminal level in order to get optimum reliability. Fortunately, dark adaptation times required to reach terminal cone threshold are not excessively long.

The working group on night vision testing plans to keep informed of the progress of Adjutant General's Office program, and to offer assistance in every way possible to facilitate the conduct of the program.

Discussion:

Dr. Miles asked if the Adjutant General's Office is still interested in night vision training.

If so, Dr. Miles asked why the Adjutant General's Office does not do its night vision testing in a training situation. The suggestion that night vision testing be carried out in the training situation was made by the Vision Committee several years ago.

Dr. Uhlener replied that the Adjutant General's Office does not necessarily want to do away with training. He emphasized that night vision testing will not necessarily be done at the time of classification of Army personnel but may actually have to be done in combat zones. Under these circumstances, the time available for administering a night vision test is severely limited and the skill of the test administrators is questionable. For these reasons, a practical test is essential.

Dr. Uhlener emphasized that actually much performance at night involves mesopic levels of luminance rather than extremely low luminance values. Thus a mesopic test should have a certain validity. Dr. Uhlener stated that the Adjutant General's Office was happy to have a working group from the Vision Committee to call upon.

Lt. Comdr. Farnsworth asked if the mesopic acuity tests would involve foveal vision.

Dr. Blackwell replied that at the levels of luminance specified, performance would probably be entirely foveal.

PERFORMANCE ON THE ORTHORATER AT REDUCED ILLUMINATION LEVELS

S. D. S. Spragg
University of Rochester

This study was carried out as part of a research contract between the University of Rochester and the Air Materiel Command, U. S. Air Forces. Mr. Joseph W. Wulfeck assisted in the experiment.

In the visual screening of subjects for dial reading experiments we tested on the Orthorater a considerable number of college students who answered the call for subjects with good vision. This method of screening raised certain questions concerning the relationships between visual abilities as measured by the Orthorater at standard brightness, and those abilities when measured at low brightness values. Accordingly, we carried out an experiment to answer the following questions: (1) how does performance on the Orthorater vary as a function of illumination level; and (2) how well is performance on the Orthorater at lower levels of illumination correlated with performance under standard brightness conditions.

Forty-eight subjects were used. Their binocular acuity Orthorater scores on the first test ranged from 9 to 15. Each subject was tested on the Orthorater six times: first at standard brightness, then at each of four lower brightness values extending down close to cone threshold, then finally at the standard brightness once more. Sequences were balanced, and each subject was tested at two brightness levels per session. A sufficient period was allowed for cone dark adaptation on the sessions at which lower brightness values were used. The tests were administered in the standard manner. Control of brightness was achieved by placing appropriate Wratten Neutral Density Filters before the entrance apertures of the Orthorater viewing box. Our measurements indicated a brightness of 15 foot-lamberts for the near tests and 32 foot-lamberts for the far tests under standard conditions. By appropriate arrangement of the filters both near and far tasks were also presented at the following brightnesses: 0.1, 0.05, 0.01, and 0.005 foot-lamberts. It will be noted that the last brightness is only slightly above cone threshold.

Results - Our analysis has been limited to the binocular results. The anticipated decrease in acuity was found at reduced brightnesses both for Near and Far. Analysis showed no significant difference between performance at Near and at Far at any of the reduced brightness levels.

Lateral phoria measurements became increasingly difficult to make below 0.1 foot-lamberts, and the results were not clear cut. What changes there were were in the direction of lessened exphoria or increased esophoria. No analysis was made of vertical phoria since (a) the scores showed extremely small dispersion and (b) almost no data were obtained below the 0.1 foot-lambert level.

The depth test was difficult to handle for two reasons. First, the progression of difficulty in the test items is not a systematic one. We decided to convert Orthorater scores into seconds of arc discrepancy and make what analysis we could. The second reason was the skewness of the scores. The results, expressed as medians, show a decrement in performance as brightness is decreased, which becomes marked below 0.05 foot-lamberts. At the lowest level tested (0.005 foot-lamberts) most subjects were unable to perform on the test.

With respect to correlations between performances, we again limited analysis to the binocular functions. Test-retest reliabilities were as follows: acuity near, .65; acuity far, .75; lateral phoria near, .70; lateral phoria far, .74. Because of the nature of the test series and the distribution of scores, a test-retest correlation for depth was evaluated by

tetrachoric r ; correlation was .63. For the acuity measurements there is a marked decrease in correlations at the reduced brightness levels. The phoria correlations did not yield much data since useable phoria measurements were not secured below the 0.1 foot-lamberts level. The correlations for the depth tests showed a steady reduction in size as brightnesses were decreased. Below 0.05 correlations with the standard brightness were not significant.

Discussion - These results indicate quite clearly the deterioration of performance on the Orthorater test as brightness is decreased. Our results, however, should be taken as suggestive rather than definitive. Our number of cases was not large and, more serious, we have a restriction of range in the subject population in addition to the restriction in scores imposed by the test itself. Within these limitations, however, it seems clear that performance on the Orthorater at standard brightness is a relatively poor predictor of performance on the same function at brightnesses of 0.01 foot-lamberts or lower.

Discussion:

- Lt. Comdr. Farnsworth expressed surprise at the low luminance values reported by Dr. Spragg for the Ortho-Rater fields. Lt. Comdr. Farnsworth reported that his experience with standard Ortho-Raters was that the luminance is approximately 200 millilamberts.
- Dr. Sloan expressed agreement with Comdr. Farnsworth. She asked what technique Dr. Spragg utilized to measure the luminance of the Ortho-Rater fields.
- Dr. Spragg replied that measures of luminance were made with a Macbeth Illuminometer placed at the subject's eye. In order to get a large enough field, a blank diffusing plate was substituted in the Ortho-Rater in place of one of the test plates.
- Dr. Spragg stated that he believed the luminance measurements he had made were entirely reliable. He stated further that Mr. Fred Jobe had reported that the low luminance values obtained were not unusual.
- Lt. Comdr. Farnsworth suggested that Dr. Spragg double-check the luminance readings, since he felt certain that the low value Dr. Spragg obtained was most unusual.
- Dr. Uhlaner commented that in considering intercorrelations between tests made at different luminance levels, it is necessary to allow for the reliability of tests at all levels.
- Dr. Spragg commented that he was aware of this fact but did not feel that he had time to discuss it fully before the Committee.

A PROJECTOR FOR NIGHT VISION TRAINING OF PILOTS

by

H. W. Rose, M.D.
Department of Ophthalmology
USAF School of Aviation Medicine

and

Horst Fleck
Research Shop
USAF School of Aviation Medicine

Introduction

In the selection of pilots the testing of night vision has been customary for over twenty years. Dark adaptation tests give good results when it is intended to exclude from pilot training the pathologic cases of night blindness. They were used with less success to grade examinees within the normal range. Successful night fighters showed good results in tests of crepuscular visual acuity tests (1-4). However, every examiner, who has repeated tests on the same individual knows that a high variability exists from day to day in all dark adaptation tests; the reason for this is not well understood. When tests are repeated, the individual shows wide fluctuations, but the average of the group shows increased ability in night vision (5). Many experts in the field of night vision now distrust the results of a single un-repeated test of night vision used to predict individual ability for night flying. There is, however, rather general agreement that, after exclusion of the pathologic cases, the training of night vision is more promising than night vision testing and selection of pilots on that basis. The peculiarities of night vision make indoctrination for night flying a necessity. This indoctrination should in part be a demonstration of night vision and can therefore be combined with training. The night vision training devices presently available in the United States are modeled after the RCAF* night vision trainer, which is based on the projection of silhouettes by means of a small bulb. It is supplemented by a slide projector using condenser and objective lens. The RCAF trainer is still a very versatile tool for training. Its only drawback is the highly stylized presentation of training objects, which makes the training material look somewhat unrealistic.

The Department of Ophthalmology of the USAF School of Aviation Medicine was asked to develop a new night vision trainer. During the initial phase various methods of presentation were tried. A working group of the Armed Forces - NRC Vision Committee consisting of Dr. William S. Verplanck, Chairman, Dr. E. Parker Johnson, Dr. P. Robb MacDonald, and Dr. Austin H. Riesen visited the USAF School of Aviation Medicine, reviewed the different methods of presentation and discussed the development in detail. The working group stressed the necessity for a comprehensive training program. It suggested use of the RCAF trainer for the time being and further development of a wide angle projector.

The projector was planned to provide, at different brightness levels, wide angle projection of black and white and color pictures with an additional movable picture of an aircraft in the same frame.

Description of the Apparatus

The trainer is an inclosed wide angle projector. A 20-volt, 100-watt bulb (A in figure 1) with small coiled filament in focusing mount is the light source. It is cooled by a light-

*Royal Canadian Air Force.

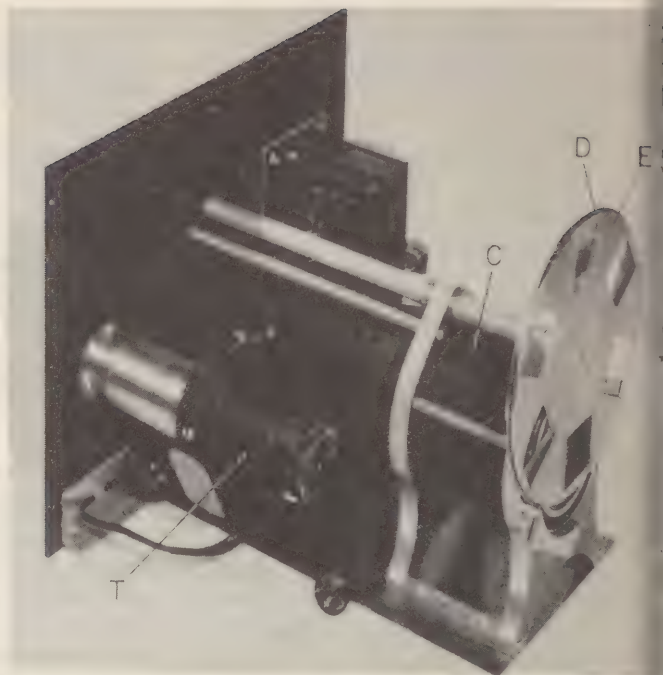
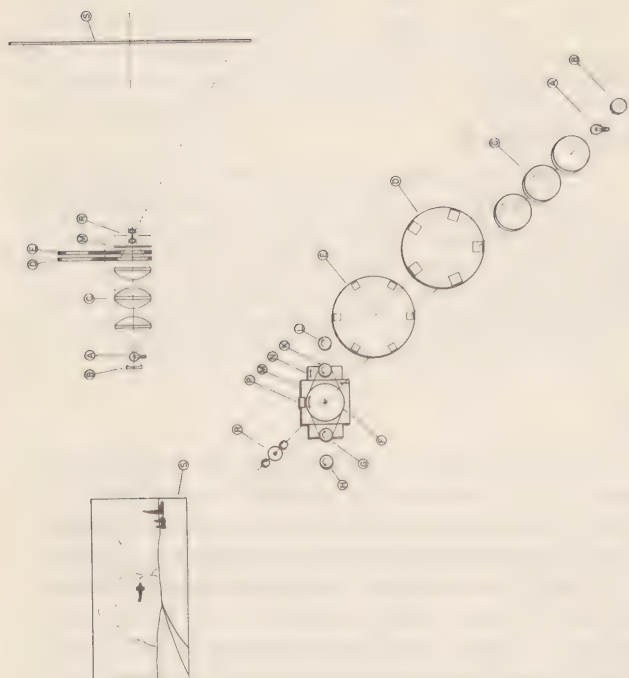


Figure 1. Cross section and exploded schematic view of night vision training projector.

Figure 2. Night vision training projector, illumination and slide changing system.

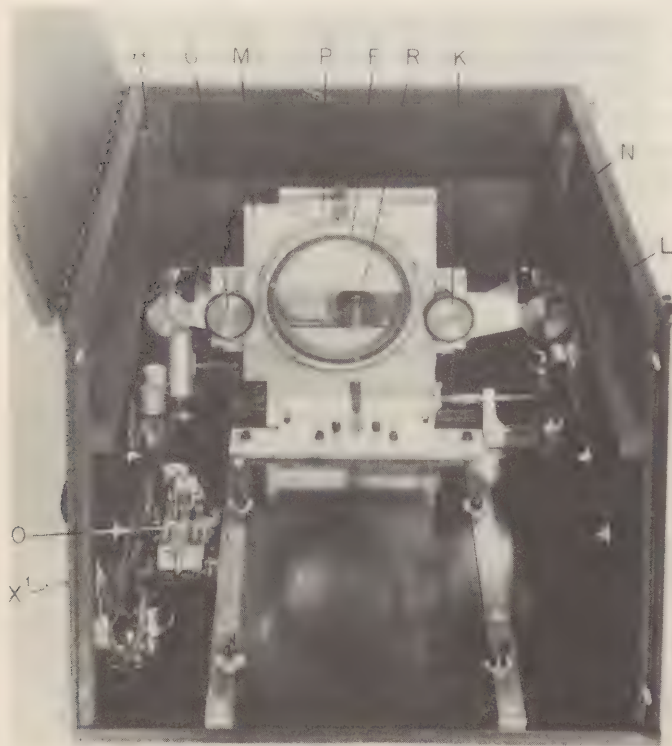


Figure 3. Night vision training projector, movable slide and objective.



Figure 4. Night vision training projector; box, glare light and lights for demonstration of autokinetic illusion.

tight blower. Back of it is a concave mirror (B). The light passes through a three-lens condenser (C, figures 1 and 2), continues through filter turret (D, figures 1, 2, and 3) and slide turret (E, figures 1, 2, and 3) goes through a second slide holder (F, figures 1 and 3). The lens (R, figures 1 and 3) forms an image of the combined slides on the screen (S, figure 1). The filter turret which is controlled by knob (U, figure 4) has five openings. One remains open, the remaining four contain filters of densities 1, 2, 3, and 4. The slide turret which is controlled by knob (V, figure 4) has six openings for slides 50 x 50 mm. (2" x 2"). The movable slide (F, figures 1 and 3) is a round glass plate of 12.2-cm. diameter on which in the center a silhouette of an aircraft is painted; this silhouette is 3 mm. long. Slide (F) is connected by means of a belt to pulley (G) and is rotated when pulley (G) touches wheel (H). Rotation in the opposite direction is provided by pulley (K) and wheel (L). The slide (F) is mounted on a slide (M, figures 1 and 3) which can be moved up and down manually by means of a knob (W, figure 5). Slide (M) and pulleys (G) and (K) are mounted on slide (N) which can be moved horizontally and is driven by a synchronous motor. The effect of the motion of slide (N) is a horizontal movement of the aircraft silhouette on the screen, superimposed on the background projected with the stationary slide. The aircraft silhouette crosses the projected image once every 90 seconds. After it leaves the visual field to the left, pulley (K) touches wheel (L) which initiates a rotation of slide (F), which is stopped after 180° turn by catch (P). Relay (O) starts then a motion of slide (N) in the opposite direction. By means of knob (W) the motion of the silhouette can be brought to various elevations, and if desired one path of the aircraft silhouette can be put outside the projected image that makes it possible to have the silhouette always come from one side or to have it change direction after each passage. The objective is a 28-mm. focal length wide angle lens f:16 from Bausch and Lomb. In front of the projection screen on the floor will be a light assembly (Y, Z, Z', figure 4). It contains a floodlight (Y) as glare source, and a single (Z') and a triple (Z) light to demonstrate autokinetic effects. The projector is contained in a light-tight box 51 cm. x 44 cm. x 36 cm. (W, figures 4 and 5) which provides space for cables, floodlight and the lights for autokinetic demonstration. On the box are mounted a main switch (X', figure 3) and switches (X, figure 5) controlling, from right to left; the motor for horizontal movement, the projector light, the glare source, the autokinetic demonstration lights.

Discussion

The projector shows, with good equality of illumination in the corners of the image, a picture of 30 mm. x 45 mm., that is 47° vertical, 58° horizontal, and 63° diagonal angle. The usual 24 mm. x 36 mm. picture or double-frame 35 mm. picture covers 41° vertically, 52° horizontally, and 57° diagonally. It is suggested that the training projector be used at a distance of 330 cm. from the screen. At this distance the illumination on the screen without slide is 2.15 lux or 0.2 foot-candles. On a good white surface that provides a maximum luminance of about 0.6 nit* without filter. With filter of density 1, the luminance is about 0.06 nit; with filter of density 2, the luminance is about 0.006 nit; with filter of density 3, the luminance is about 0.0006 nit, and with

*1 nit 3.14 apostilbs : 3.14×10^{-4} lamberts

1 candle per m².

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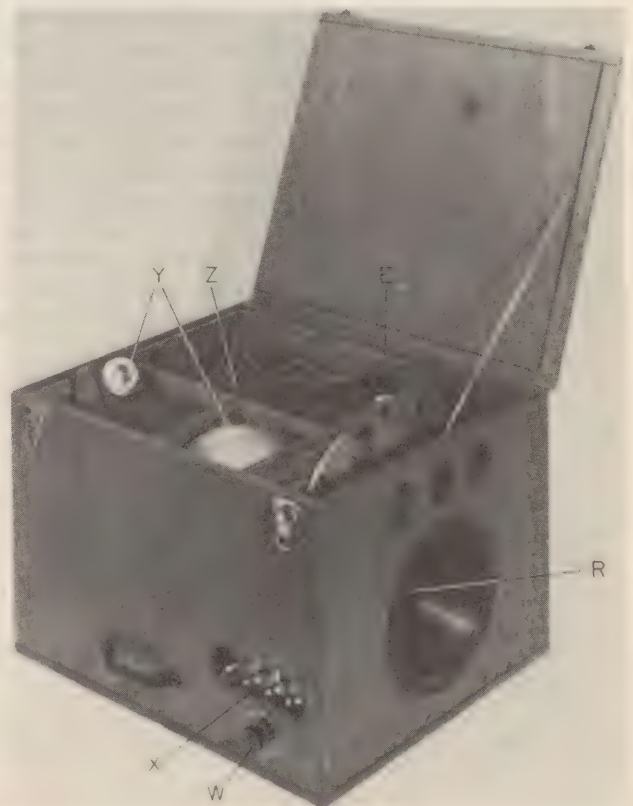


Figure 5. Night vision training projector, packed box.

filter of density 4, the luminance is about 0.00006 nit. The maximum luminance without filter and with filter 1 is in the range of mesopic vision; that is, the transition zone of cone and rod vision and color is visible. Filters 2, 3, and 4 bring the luminance down to pure rod vision.

It is suggested that this training projector be used in a comprehensive training program consisting of lecture, demonstration, and training. With the projector, the following can be shown:

- a. Dark adaptation.
- b. Off-center vision.
- c. Decline and loss of color vision.
- d. Purkinje's phenomenon.
- e. Decline of visual acuity.
- f. Increase of contrast threshold.
- g. Usefulness of scanning methods.
- h. Effect of short-time glare and recovery after it.
- i. Local adaptation.
- j. Autokinetic illusion and prevention by use of multiple lamp installation.

The demonstration and training procedure should begin with the brightest setting of the projector (no filter). Slides of landscapes, airports, etc., in color should be used to point out color, relative brightness of colors, and small features of the landscape. The brightness of the projection picture should then be gradually diminished, and the trainees should be made aware of the ensuing loss of color, visual acuity, and contrast discrimination. The Purkinje phenomenon should be pointed out. The adaptation could be shown by having each slide projected with a certain brightness for some time. During that time scanning and off-center vision can be trained. The autokinetic illusion can be shown with the single light (Z') and its prevention can be demonstrated by switching on the three lights (Z). Near the end of the demonstration and training session the floodlight (Y) should be used to show the afterimage, the effect of short-time glare, and the recovery of night vision. The prevention of glare effects by closing one eye or by using red goggles can be demonstrated at this time.

For the production of this projection trainer, it is suggested that the projection lamp and the fan cooling it, which both use 20 volts from a transformer, be changed to 115 volts. The 20-volt projection bulb should be retained only if it is impossible to procure a very small 115-volt light source. The condenser housing should be redesigned and simplified. The movable slide should be made photographically, and the aircraft silhouette can be reduced to 2-mm. lengths.

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5. Mulzer, J. Unpublished report quoted from H. W. Rose, "Night Vision" in German Aviation Medicine World War II, Vol. II, page 946. Washington: U. S. Government Printing Office, 1950.

Discussion:

- Col. Byrnes commented that the instrument described by Dr. Rose represents the end product of advice rendered by the Vision Committee to the Air Force on the problem of a night vision trainer.
- Dr. Verplanck congratulated Dr. Rose for the fine job he has done in carrying the night vision trainer to completion.
- Group Capt. McCulloch inquired as to the angular subtense of the field and the approximate cost of the objective lens used in the instrument.
- Dr. Rose replied that the angular subtense of the field was 47° in the vertical dimension and 58° in the horizontal dimension. The usual Leica field is 41° vertical and 52° horizontal. The cost of the objective lens was approximately \$200. Dr. Rose commented that it might be possible to use a simpler condenser lens. He took available lenses in order to shorten the time required to ready the device.
- Dr. Gordon asked if Dr. Rose had any plans for validating the trainer.
- Dr. Rose replied that no plans for validation had been made, but that such a study should be done.

ROTATOR AND ILLUMINATOR OF PLATES FOR TESTING COLOR VISION

by

Ingeborg Schmidt

In the general endeavor to standardize the fitness examination and to exclude as much as possible the individuality of the examiner and the examinee, a Rotator and Illuminator for pseudoisochromatic plates was designed. This apparatus provides standardization in respect to exposure time, illumination and arrangement. The charts are fastened on metallic plates rotating alternately with blank plates of gray color. Each plate remains stationary for 3 seconds and then turns automatically. The demonstration plate is presented in the standstill position. To start the mechanism, a pushbutton is depressed which over a relay will set the motor and timer in motion. After the complete cycle the mechanism stops, showing again the demonstration plate. A fluorescent daylight tube with reflector at a fixed distance provides a diffuse and constant illumination of the desired foot-candle, and color temperature. The rotator and the illuminating bulb are mounted in a box. The apparatus can be used in a daylight room or in a dark room. In the dark room the record form of the examinee must be illuminated by a daylight lamp. By means of a chinrest and a slight slope of the plate, a 90 degree viewing angle of the examinee is obtained. A chain connecting the box and the chinrest establishes the distance between the observer and the plate. The observer records his reading on a form placed on a small movable stand. The apparatus is especially adapted for routine examination, but can also be used for demonstration in classes.

Its application is manifold also in research work, for instance, in obtaining data on the diagnostic efficiency of individual plates.

Discussion:

- Col. Byrnes commented that the self-contained color vision tester represents another completed project which grew out of Vision Committee interest. Lt. Comdr. Farnsworth had often expressed the idea that someone should build a self-contained color vision tester and now the job has been completed.
- Dr. Judd asked Dr. Schmidt if she had any information as to why the hidden digit plates are easier to read with short exposures than with long exposures. On the face of it, this seems a startling result.
- Dr. Schmidt replied that she believed the explanation lay in color adaptation. The color defectives lose color experience quickly in the red and green.
- Dr. Judd commented that this explanation applies only to anomalous trichromats.
- Dr. Clement Brown asked if the device would not be improved if the illumination were cut off during the plate changes.
- Dr. Schmidt replied that she believed it better to put a blank plate in between the test plates rather than to turn off the illumination.
- Lt. Comdr. Farnsworth expressed his satisfaction with the instrument and stated that he hoped other suggestions he may make in the future will turn out as well as this one.
- Dr. Sloan expressed considerable concern over the fact that the color vision tester does not permit one to change the order of the plates in successive test administrations. She

expressed her opinion that she would trade the mechanical features for the ability to be able to change plates.

- Col. Byrnes commented that it would be possible to use a battery of color vision testers in a testing installation, each of which had plates in a different order. In this way, a testee could not possibly malingering.
- Dr. Wolpaw asked if the gain in ability to administer color vision tests warrants the expense of the tester.
- Dr. Miles stated his opinion that the expense is definitely justified, because the test forces the testee to make his responses within a given time. Anyone who has tested color deficient knows how the testing time tends to drag out. The color anomalous will obtain additional time and will improve his score as a consequence.
- Lt. Comdr. Farnsworth stated his conviction that the improvement in color vision testing easily pays for itself. For example, Lt. Comdr. Farnsworth cited the case history of a man during the last war who wanted to get into the Navy. In order to qualify himself, he went to training school at his own expense. He enlisted and was tested for color vision and found to be normal. After considerable further schooling within the Navy, he was retested and it was found that he was color deficient. This man had to be assigned to scraping boat hulls. The loss in training expense in men like this should more than compensate for the expense involved in developing a machine test.
- Col. Byrnes remarked that there would be no particular advantage of the tester for vision specialists but that when color vision testing must be done by technicians, some kind of mechanization is necessary.
- Dr. Miles commented that it would be desirable to develop a demonstration to use when informing a man that he is color deficient. The color deficient person should be made aware of the extent to which he is not normal in this respect. A special slide could be developed with an auxillary filter. Without the filter, the man would not be able to discriminate colors, but when the special filter was introduced, the color differences would suddenly become apparent to him. Such a demonstration would make the nature of color deficiency obvious to the candidate.

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THE EFFECT OF VIEWING ANGLE AND PARALLAX UPON ACCURACY OF READING QUANTITATIVE SCALES*

Jereome Cohen, Antioch College
William J. White and James M. Vanderplas, Aero Medical Laboratory,
Wright-Patterson Air Force Base

INTRODUCTION

An important condition which affects the accuracy of reading of instruments which present quantitative information is the position of the instrument with respect to the observer's line-of-sight. When an instrument is displaced from the point immediately in front of the observer, and if the pointer and the plane of the dial are also displaced, the viewing angle is decreased and parallax is introduced. It is well known that such decreases in viewing angle and introduction of parallax affect reading accuracy, and manufacturers of precision instrument scales take considerable pains to eliminate these factors on scales which are to be read to close tolerances. In the more common situation, however, where several instruments are displayed on a panel, as in aircraft, the position of the dials is such that some of the dials are displaced laterally to the line-of-sight and it is not feasible to construct instruments with precise pointer-locating devices on them, such as mirrors, etc. The usual design practice has been to attempt to restrict the location of instruments which require fairly great accuracy in reading to the center of the instrument panel, to avoid the problem of parallax for at least some instruments.

PURPOSE

It is the purpose of this paper to report on two exploratory studies designed to describe the changes in reading accuracy which might be expected as functions of decreasing viewing angle and the introduction of parallax.

DEFINITIONS

By viewing angle we mean the acute angle formed by the intersection of the plane of the dial face and the observer's line-of-sight. Thus, a viewing angle of 90 degrees would indicate a head-on position with the dial face normal to the line-of-sight. As the dial is rotated or moved from this position the viewing angle would decrease.

By parallax we mean the amount of displacement of the pointer from the plane of the dial face. There appear to be several ways to define parallax which lead to some interesting relations. These definitions, in terms of the visual angle subtended by the pointer-dial face displacement, however, have not been too satisfactory for predictive purposes, and for this report we shall confine ourselves to the displacement definition.

THE EXPERIMENTS

Two experiments were performed. The first was designed to determine the effects of changes in viewing angle upon reading errors with parallax effects ruled out of the situation. To rule out the effects of parallax, photographs of dials were used. The photographs were presented in a tachistoscope and read at various viewing angles. Twenty Antioch College students were used as subjects in the experiment. All had normal Snellen acuity and none had any obvious visual defects. The apparatus consisted of a sliding mirror tachistoscope

*The experiment reported here was performed at Antioch College, Yellow Springs, Ohio, as part of service contract AF-18(600)-50. The paper describing the research was presented to the Vision Committee by Dr. Vanderplas.

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with a switching mechanism so that the subject could control the exposure time. The back of the achistoscope was arranged so that the photographs could be presented at all viewing angles between 90 and 25 degrees, rotated either horizontally or vertically. Ten of the subjects read the dials tilted horizontally, and ten read them tilted vertically. Viewing distance was 28 inches, and the brightness of the white parts of the dials was 7 foot lamberts.



DIAL TYPE 1
600 X 10



DIAL TYPE 2
400 X 10

FIGURE 1. DIAL TYPES USED IN EXPERIMENT I.

Two kinds of dials were used in the experiment, as shown in the first slide (Fig. 1). One was a 600 x 10 dial, and the second was 400 x 10. Each subject was given ten practice trials to familiarize himself with the dials of the apparatus, and was instructed to read the dials to the nearest half graduation interval, or to the nearest five units, as accurately and quickly as possible. Each subject was given 40 test trials, 20 on each of the two dial types, 4 at each of 10 viewing angles used. Five of the pointer settings for each dial type were presented in each of the quadrants of the circle.

For each dial, half of the settings were nearest a graduation mark, and half were nearest a mid-mark position. On each trial the subject pressed a switch, opening the shutter and exposing the dial. When he had read the setting, he released the switch, closing the shutter, and reported the apparent setting to the experimenter, who recorded the setting report and the time.

Results of the first experiment:

Analysis of the data revealed no systematic change in reading time as a function of viewing angle within the limits studied. A fairly systematic trend exists, however, for errors. The next slide (Fig. 2) shows a graph of the percentage of errors of five or more units made at each viewing angle. It can be seen from the graph that the errors are relatively small throughout, but there is a fairly definite increase in the slope of the curve as smaller viewing angles are approached. The increase in errors is significant beyond the 5% level as tested by Chi-square, and the data are fitted reasonably well by a cosecant function. They might also be fitted by a straight line, but on logical grounds, since the retinal projection of the mark separation distances decreases proportional to the sine of the viewing angle, we would expect errors to be inversely related to the sine function, or proportional to the cosecant. At zero degrees viewing angle, of course, the cosecant function is infinite, and we would expect errors to be extremely large or erratic, since the mark separation would be zero, and the dial face would not be visible.

The second experiment which we performed was designed to isolate, if possible, the effects of the introduction of parallax in various amounts upon errors in pointer location. It was felt that the effects of parallax could be studied best in a situation which was fairly simple and in which such errors as interpolation, numeral identification and other factors were not present. Apparatus was therefore designed so that the subjects could align a pointer with a single mark against a homogeneous background, on the assumption that the setting errors thus measured would reflect the errors in perceived location.

The apparatus for this experiment consisted of a white cardboard upon which was

painted a single black line 3 inches high by 1/8 inch wide. A black pointer of similar dimensions was set in front of the mark on a track, so that the pointer could slide laterally in front of the mark and background to various positions. The subjects controlled the position of the pointer by pulling on a pair of strings, and the experimenter could read the position of the pointer from behind the apparatus by referring to a meter stick calibrated to the pointer position.

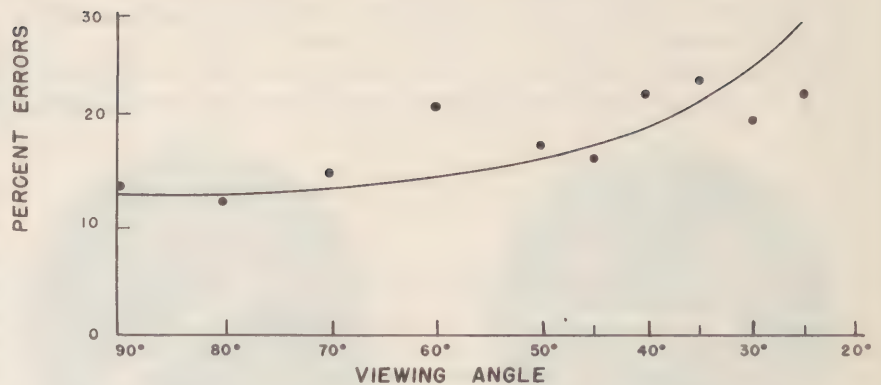


FIGURE 2. PERCENT READINGS IN ERROR BY 5 UNITS OR MORE AT EACH VIEWING ANGLE. EXPERIMENT I

Subjects were asked to set the pointer on a line perpendicular to the plane of the mark and in line with the mark, with the panel set at viewing angles from 90 degrees to 20 degrees, both left and right. Pointer and mark were displaced by distances of 1/4, 1/2, 1, and 1 1/2 inches. Viewing distance was ten feet. Two settings, left and right, were made by each subject at each of nine viewing angles, left and right, and at each of the four displacements, a total of 136 settings per subject. Sequence of presentation of the viewing angles, displacements, and left and right settings was randomized for each subject.

Results of the second experiment:

A preliminary analysis of the error data revealed that the distributions of errors at each viewing angle were neither normal nor homogeneous with respect to variability. The distributions were fairly symmetrical at the 90 degree position, but as viewing angle was decreased the distributions became both more skew and more variable. For this reason the medians were used rather than the means as average measure of errors at each viewing angle and displacement.

In the next slide (Fig. 3), the data are presented in terms of the median constant error (in which direction of error is considered) as a function of viewing angle, for the four pointer-mark displacements used. The zero point indicates a correct alignment, positive values indicate settings in the direction away from the observer, and negative values indicate settings toward the observer, relative to correct alignment.

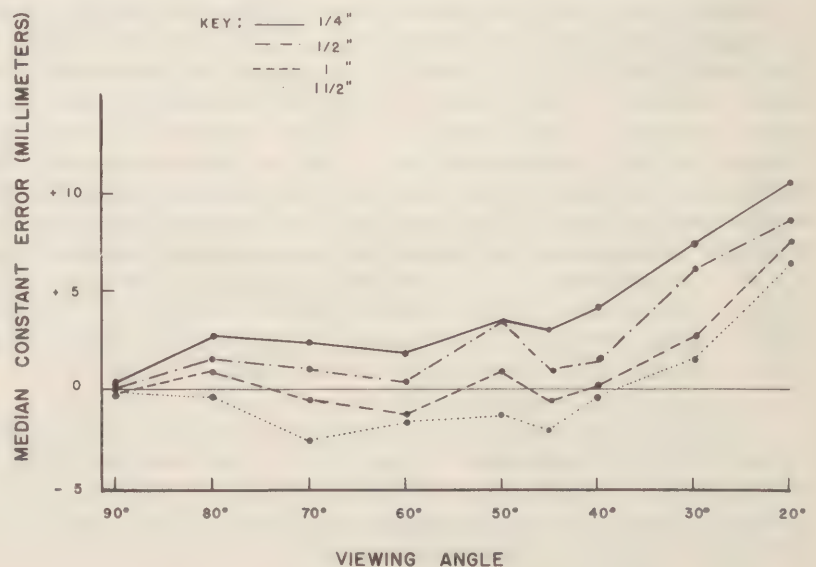


FIGURE 3. MEDIAN CONSTANT ERROR FOR EACH POINTER-MARK DISPLACEMENT AT EACH VIEWING ANGLE

It can be seen from the graph that a trend exists here similar to that found in the first experiment, namely, increasing

error with decreasing viewing angle. In addition, there appears to be an inverse relation between constant errors and displacement, the small displacements yielding apparently greater positive constant errors, while the large displacements yield small or negative constant errors (in the direction of the observer).

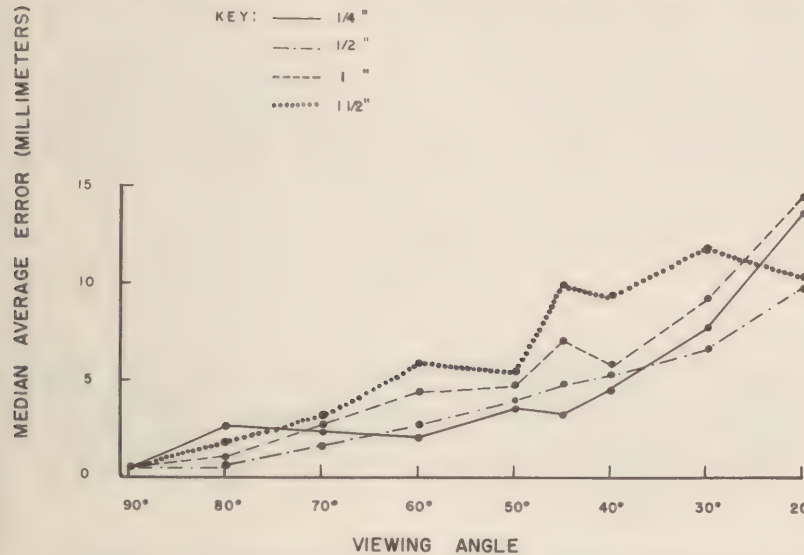


FIGURE 4. MEDIAN AVERAGE ERROR FOR EACH POINTER - MARK
DISPLACEMENT AT EACH VIEWING ANGLE.

error, appears inversely related to the amount of displacement.

If all of the data are combined, and the median average error is plotted as a function of viewing angle for all displacements combined, the data as shown by the next slide (Fig. 5) appears. The curve fitted here is again a very close approximation to a cosecant function, and it appears to fit the data quite well, and in about the same way as in the first experiment.

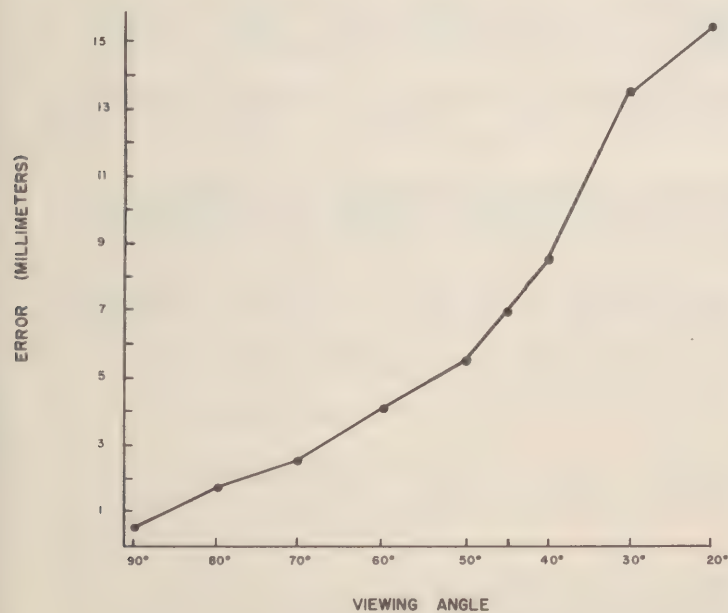


FIGURE 5. AVERAGE OF SEMI-INTERQUARTILE RANGES FOR ALL DISPLACEMENTS

A similar trend appears for errors to increase as a function of viewing angle if the median average error (in which direction is not considered) is plotted. The next slide (Fig. 4) shows a graph of this function plotted for the four displacements. The relation of amount of displacement to error is not so clear here as it was for constant error. There appears here to be a reversal of the former trend, and errors tend to increase with increasing displacement of pointer and mark. It might be said that the variability increases with greater displacement as indicated by the average error, but that the direction of the error as indicated by the median constant

DISCUSSION

There appear to be at least two effects involved in the experimental data. The first is the effect of decreased apparent distances between successive points on the scale as a function of decreasing viewing angle; the second appears to be the effect of displacement between the pointer and scale planes. Apparently, for the limits of this study, large pointer displacements lead to small constant errors, but large variable error, while small displacements lead to large, and consistent constant errors. This finding is pointed out by the apparently small constant errors of the greater displacements, when compared with their average errors.

The important question we think

is whether the effects of viewing angle and pointer-mark displacement are independent effects, or whether they can be predicted only on the basis of a joint function, and this is a question which we intend next to explore. Some tentative theoretical functions have been constructed, starting from a definition of parallax in terms of the visual angle subtended by the pointer-mark displacement. A study is planned to determine the joint effects of decreased viewing angle and introduction of parallax (in these visual angle terms) simultaneously in a scale reading situation, and to test the predictive ability of the joint, but independent, error functions generated for viewing angle and parallax. It is hoped that such an approach will serve the two-fold purpose of providing a better basis upon which to predict the errors to be expected in a practical sense, and also to provide a better understanding of the functional relationships involved.

Discussion:

Mr. Middleton stated that he would like to ask some questions which would occur to a physicist. First, is the simple setting of two black marks the same thing as reading a scale when you have lots of marks. Second, if a man were not working in a psychological experiment, would he not try to set the pointer at right angles to the scale in order to get the right answer rather than to report what he sees.

Mr. Middleton questioned the applicability of the results of the present experiment to practical instances in which men are required to read scales.

Dr. Vanderplas stated that the present study was intended to evaluate several possible mechanisms which a subject could use in working scales. In the first place, the subject could have perceptual constancy and make a correction in order to put the pointer where it belongs rather than where he sees it. Secondly, the subject might not have perceptual constancy. There are very few studies concerned with the extent to which constancy exists when reading a scale involving parallax error.

Col. Olson asked why the experiment was conducted at 10 feet.

Dr. Vanderplas stated that the experiment could have been done at 28 inches and in fact, this might have been better. The apparatus had been designed in terms of 10 feet.

Mr. Breckenridge asked if the results had been analyzed in terms of a purely geometric interpretation of the results.

Dr. Vanderplas replied that such an interpretation had been attempted in the present case but that it was not possible to account for all the "wiggles" in the curves on the basis of a geometric interpretation.

Col. Byrnes asked how large the angular displacement is in actual Air Force instruments.

Dr. Vanderplas replied that in some cases, the displacement is as great as 30-40°.

EYE MOVEMENTS DURING RADAR OBSERVATION

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The knowledge about eye movements during radar observation may be useful in two respects: first, it may improve our insight into the visual problems of the detection of targets; and secondly, it may serve to throw some light on the problem of visual fatigue.

As a radar observer searches the PPI-scope for targets, he must continually keep his eyes roving over the screen hunting for new pips. Unofficial operational accounts and comments of military authorities agree that the efficacy of the observer is sometimes poor and that he complains about early fatigue, headache, drowsiness, and similar schemes of operational disturbances. It has been suspected that these disturbances are caused by the electrical events in the device, but this is very unlikely. We believe that one solution of this problem may be found in the nature of the eye movements, and we think that the study of the basic eye movement pattern during radar observation will clarify our understanding why targets are or are not picked up and why visual fatigue occurs under certain conditions.

Method

For the experiments, a Master Ophthalmograph (American Optical Company) and a Supersonic Trainer with tank and driver and crystal unit were used in such a way that the scope was seen in a mirror mounted in the field of observation. The apparent distance of the radar scope from the observer's eyes was about 14 inches. Time was made by a propeller which interrupted the reflected light beams at intervals of 0.5 seconds. The experimental set-up is shown in picture 1. The experiments were conducted by Dr. Strughold, Department of Space Medicine, School of Aviation Medicine, and the author.

As far as the recording technique is concerned it must be pointed out that two light beams are projected upon the eyes and their reflections from the cornea are focused on the film. Figure 2 illustrates the scheme for photographing eye movements. From this it can be seen that when the eyes turn to the right, the corneal reflections on the film move to the left and vice versa. The same reversal of direction holds for movements in the vertical meridian. Some examples for the basic eye movement patterns are shown in Figure 3 (eye movements during reading), Figure 4 (horizontal), Figure 5 (vertical), Figure 6 (diagonal), Figure 7 (following out squares), Figure 8 (hexagons), Figure 9 (octagons), and finally, Figure 10 (circles of various diameters).

It is these "circular" eye movements in which we were interested the most because, as we had pointed out before, the sweep line is continually rotating around the center of the scope or passing over only one sector of the scope exiting the screen in one direction only. The first type of sweep is used most of the time. We assumed that the radar observer's eyes follow the sweep in jerks and tried to keep pace with it. A method was developed for photographing these "circular" eye movements with the film at rest and with the film moving.

The following steps seemed to be necessary:

1. Recording eye movements when the eyes were moved around an imaginary center within the visual field; when tracing a circle, and when following an object moving in the orbit of a circle.
2. Recording the eye movements during observation on the radar scope. For the first part of the study, the assumption was made that recordings of unguided, partially

guided, and pursuit movements will serve our interpretation of the data obtained in the second part, namely during operational tasks on the scope. This assumption was proved to be valid.

For a systematic analysis of the second point, the following individual tasks were assumed to be of importance: (1) orientation, (2) navigation, (3) target identification, and (4) bombing. These four tasks were derived from the literature on operational radar and from on-the-job discussions with radar observers. A short outline will be given for each of these operations as used in our experiments.

1. Orientation: The orientational task consisted of matching a picture of the Supersonic Map with the returns on the PPI-scope. The map used in the experiment can be seen in Picture 11, and the radar picture is displayed in Figure 12. The antenna of the trainer was set in a stationary position over a characteristic bay. The subject had to orient himself on the scope, and to state after the experiment where the antenna had been placed. Three orientation tests were made by five subjects who were not trained as radar observers. Their eye movements were filmed during the periods of orientation.

2. Navigation: In this task tracking the flight course was considered to be the most essential part. It is the factor of motion in flight which was investigated in the experiments. The subject was told that a simulated flight was made over a characteristic part of the map, and that he had to find out by observing the scope picture in which direction the airplane was heading.

3. Target Identification. Here, three simple geometric targets were arranged in a certain pattern within one of the bays and the subject had to identify the pattern and the shape of the individual targets. A picture of this test is given in Figure 13.

4. Bombing: The eye movements during a simplified simulated bomb run were recorded with the continuous rotating sweep and with the sector sweep in use. The observer fixates the target very strictly during the last phase after the IP has been passed. He was instructed to release the bombs when the bombing circle comes in contact with the periphery of the target. Examples of this test are given in Figures 14 and 15.

Results

Eye movements in following a circle have been previously recorded by Stratton (1906). He found that the eyes are unable to perform a perfect circle, but follow principally the cardinal directions in jerks. In Figures 16 and 17 eye movements with different degrees of guidance are displayed which show that the regularity of the movements increase with an increase in guidance. Figure 18 shows the same effect recorded on a moving film. On the other hand, regularity and smoothness of the movements also depend upon the speed of the sweep, in case of pursuit movements; and the relation of two of our criteria -- namely, number of fixations and extension of the interfixation movements -- to sweep speed is demonstrated in Figure 19. So much about circular eye movements.

Eye movements during orientation. As can be seen in Figure 20, there are sequences of circular and linear eye movement patterns on the films of all five subjects. This kinematic pattern was called L-C periodicity for the purpose of our quantitative evaluation. A circular period occurs, when the eye is scanning the scope; a period of linear fixations occurs when the eye is anchored at one or more conspicuous reference points within the observed area.

Eye movements during navigation. The samples given in Figure 21 were taken from the same subjects and represent about the same phases of observation within this task. Here, the linear phases prevail over the circular periods. Moreover, the fixation periods

are slightly longer than those during orientation. Furthermore, the interfixation movements are found to be larger in extent than those made during scanning; the latter may be brought about by jumping from one reference point to another.

Eye movements during target identification. Practically no circular movements can be found in Figure 22 except those just before the beginning of the identification phase on strip Ca. Horizontal and diagonal movements dominate, indicating that the eye is switching from one of the three targets to the other. Again, the fixation periods are prolonged.

Eye movements during bombing. Both Figures 23 and 24 show almost straight and parallel traces of fixation. As a rule, the angle of extension seldom exceeds 20 seconds of arc. Two subjects reported the feeling of being more distracted by the sector sweep than by the rotating sweep and of involuntary eye movements in the direction of the sweep.

The numerical results of the five experiments are given in Tables I through V. The following criteria were applied for the evaluation: (1) periodicity of circular and linear eye movements, (2) number of fixations per second, (3) duration of fixation, (4) interfixation time, (5) direction of eye movements, (6) synchronization, and (7) stability of fixation. Only mean values were computed and, since the evaluation technique was considered as very crude by the investigator, the data were not treated statistically. It seems doubtful that a more detailed analysis would add substantially to the information already obtained. Our records reveal that we have different kinds of eye movements during radar observation. They serve the purpose of either scanning the screen or probing the target.

No information was available to the author on the frequency and duration of the four individual tasks during a long-range mission. We have reason to assume, however, that orientation and navigation will dominate, and that the periods of target identification and bombing are relatively short. This would indicate that the radar observer follows the sweep involuntarily, most of the time executing circular eye movements imposed by the sweep, which may cause visual fatigue and drowsiness by the rhythmic excitation. According to our findings with untrained observers, about as many circular periods occurred as linear ones during the orientational and navigational tasks. During a period of four hours work in actual flight, e. g., the eyes may execute these unnatural movements for about two hours, resulting in a total of about 7,000 jerks. This in itself suggests that during a longer period of observation by radar the efficiency of the operator may be impaired because of the physiological stress, imposed by this kind of eye movements.

Summary

The eye movements involved in radar observation are much more complex than under normal observational conditions. Using a Master Ophthalmograph in combination with radar equipment, eye movements were recorded during basic patterns and during simple tasks of orientation, navigation, target identification and bombing missions.

Special attention was given to the duration and number of interfixation movements and fixation phases, direction and kinematic pattern of the movements, as well as their stability and synchronization. The following results were obtained:

1. During radar observation the eyes do not "ride the sweep" as sometimes erroneously assumed; rather they follow the sweep in jerks, the number of which per second depends mainly upon the operational task. This number is highest during orientation and decreases with navigation and target identification. No circular eye movements were recorded during bombing.
2. The duration of the movements depends upon their extension. During orientation,

navigation, and target identification, the interfixation time amounted to about 30-35 milliseconds; during bombing, to about 20 milliseconds.

3. The duration of fixation also depends upon what the observer is after. It increases from about 430 milliseconds during orientation, to about 475 milliseconds during navigation, to about 830 milliseconds during target identification, and finally, to about 1270 and 1815 milliseconds, respectively, for the two types of sweep movements during bombing.

4. Synchronization of the movements of the two eyes and stability of fixation declined with increasing angle of extension and frequency of eye movements.

5. The opinion has been expressed that straining the eye muscles in such an unusual manner as by continuous radar observation over a long period of time may cause fatigue and drowsiness of the observer. Limitation of the observation time with rotating sweep, and concealing or omitting the bright sweep line will help to prevent early psychophysiological disturbances.

Discussion:

Col. Byrnes asked if any studies had been made of fatigue before and after observations of the radar.

Dr. Gerathewohl replied in the negative.

Dr. Miles asked whether Dr. Gerathewohl believed circular scanning to be necessary for orientation. The pips are presented for a comparatively long time and therefore the observers could use vertical and lateral eye movements for orientation purposes.

Dr. Gerathewohl replied that it was his belief that circular eye movements are very bad because of the excessive fatigue which they produce. Furthermore, efforts should be devoted to eliminating fixational skips. In most of the cases, the radar observer is looking at the scope constantly. If the periods of observation could be reduced so that the scope was in front of the eye only when needed, the fatigue would be reduced.

Dr. Hulburt asked if observing a radar-scope is any different from reading a book for two hours.

Dr. Gerathewohl stated that he believed there to be an important difference. In reading a book, the eyes make only horizontal or vertical movements whereas in the case of the radar-scope, the eye is required to make unnatural movements of a circular variety.

Mr. Breckenridge stated his belief that the blurred nature of the pip resulted in fatigue.

Dr. Gerathewohl stated that he did not believe the reduction in contrast due to blurring caused fatigue.

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A DISCUSSION OF PROBLEMS RELATED TO CATHODE RAY TUBE SIZE AND OTHER CHARACTERISTICS OF RADAR SCOPE DISPLAYS

WALTER F. GRETHER

Presented by Dr. J. M. Vanderplas

Introduction

The purpose of this paper is to present a problem, rather than results. Although the discussion will be centered around the radar scope used in Air Force bombing, it is believed that the basic problem is a very general one in the field of vision. It is hoped by this presentation to develop interest and helpful discussion. The problem I wish to discuss is the optimum size of the Cathode Ray Tube (CRT) display for use in bombing.

General Characteristics of Radar Bombing Scopes

The picture on a radar bombing scope presents two dimensions of space, azimuth and slant range. In essence it is a crude map of ground features with geometry comparable to that of a map and quite different from that of an oblique aerial photo. In appearance, it may be described as a miscellaneous conglomeration of blobs, which to the uninitiated have little resemblance to anything. Only where there are land water boundaries do any sharp contours or borders appear in the radar picture. In general, one can describe the radar picture as somewhat fuzzy, without sharp edges on contours. Yet it does contain a large number of pips or blips, which the experienced radar observer can interpret in terms of terrain features, buildings, bridges, railroads, etc.

There are two major factors which limit the clarity or resolution of the radar scope picture. The first of these is inherent in the radar technique itself. No matter how small a target, the blip on the scope will be spread out in azimuth proportional to the angular width of the radar beam. In range the target blip will be spread out proportional to the length of the radar pulse. The second major factor causing fuzziness of the picture is the minimum spot size of the electron beam and phosphor combination of the CRT used to display the radar returns. Although some improvement appears possible in these determinants of picture resolution, for purposes of this discussion we will assume that these physical factors place a lower limit on resolution.

Recent Interest in Increased Radar Scope Size

At the present time the standard bombing radar scope is a 5-inch cathode ray tube giving the standard plan position (PPI) indication. For the bomb run this is changed to an offset sector scan. In some cases the final bomb drop is accomplished with a B scope (rectangular) presentation. Recently there has been a demand from some operational groups for a larger 10-inch diameter scope. At first glance it seemed to some of us that the mere enlargement of a somewhat fuzzy picture, apparently already above threshold, should not significantly benefit the observer. Engineers assured us that mere use of a larger scope would not increase the total physical detail or information in the picture. Superficial tests, however, with magnifying lenses and larger tubes on simulators, suggested that mere enlargement somehow made it easier to see and interpret the scope picture. In the meantime an enterprising group at Mather AFB installed a large ground radar tube in a radar trainer aircraft. Although all physical characteristics, other than size, could not be held constant, it was generally agreed that the larger scope was more satisfactory, and that it improved the observers ability to interpret the complex radar picture. Because of this and similar evidence the Air Force is now proceeding with the development of 10-inch CRT's for future bombing use. There has, however, been no satisfactory determination of what the optimum size of a bombing radar scope should be, nor do we know with confidence how to determine this optimum size.

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Related Problems in Size of Visual Displays

The scope size problem discussed above is analogous to other visual display problems. We know from the thorough work of Patterson and Tinker on size of print that 10 point type is the optimum size for normal use. This size is far above threshold visual acuity at normal reading distance. I think most people will agree that an enlarged photograph is preferred over a small print with equal detail. In television we have had a rapid transition to larger tube sizes, even though the picture detail is not increased by the mere change in size.

Statement of Problem

The general problem to which I wish to call attention is this: In a picture, radar scope, or other visual display, how can one predict optimum size? What is the relation between the optimum size and threshold size? In considering these questions one must, of course, hold constant such physical variables as viewing distance, illumination, contrast, and total detail present in the display.

Variables Which May Determine Optimum Size

Visual acuity and brightness Discrimination

It seems clear that in this type of problem we are dealing with the two closely related processes of visual acuity and brightness discrimination. In such a complex picture as a bombing radar scope we have innumerable brightness gradients. With such a situation it is difficult, if not impossible, to determine when the visual acuity threshold has been reached as the over-all size is increased. As a given brightness gradient is expanded over greater space, when have we reached the maximum visual resolving power for the pattern?

Visual Acuity and Distance From the Fovea

Visual acuity thresholds are normally defined in terms of acuity at the fovea. We know, however, that acuity falls off rapidly to a low value with eccentricity from the fovea. This may be a significant factor when dealing with a pattern which covers a considerably larger angle than the fovea. Although all elements of the pattern may be well above threshold for the fovea, enlargement of the pattern may place a greater proportion of the total area above threshold during a single fixation, even though such an enlargement also increases the total distance between elements. We have made a partial test of this point by applying Wertheim's data to a Landolt ring with fixation not at the break, but at the center of the ring. The above prediction was born out. The curve for minimum separable visual angle increases less rapidly with distance from the fovea than does the physical gap in the ring as the ring is enlarged. From this it appears that enlargement of a picture above the size required for foveal resolution will make a greater proportion of the pattern resolvable at a single fixation. Probably there is some optimum size range beyond which there is a loss in the proportion of the total area which can be seen clearly.

Visual Fatigue and Proximity to Threshold.

A final variable which I hesitate to mention, is the possible relation between visual fatigue and proximity to threshold visual conditions. Where patterns must be viewed for prolonged periods, as in radar navigation and bombing, fatigue becomes a real problem, although difficult to measure. It appears likely that fatigue will be less severe with a large picture, with all details well above threshold, than with a small picture with the pattern approaching the limits of visual acuity.

Discussion:

- Col. Byrnes commented that Col. Grether's paper is concerned with a very real problem which exists in the Air Force.
- Dr. Gerathewohl commented that studies had been made at Randolph Field to determine the effect of the size of scope upon number of errors. It was found that as the size of the scope increased, the number of errors decreased.
- Dr. Crozier commented that he has always been skeptical of forecasting acuity from data on minimum resolvable angle. For example, if one determines the illumination required to resolve a series of parallel black bars, one can then erase one of the bars and improve acuity.
- Dr. Blackwell commented that there is another variable involved in actual radar when one increases the size of the radar-scope. The physical sharpness of the gradient will decrease as the scope size increases. In the experimental set-ups, no allowance was made for this variable.
- Dr. Blackwell also asked whether anything is known concerning the pattern of eye movements for different size scope faces.
- Dr. Vanderplas commented that nothing was known about this aspect of the problem.
- Dr. Harker asked whether Dr. Vanderplas had considered attempting to predict results in experimentation of this sort on the basis of modern theory of information communication.
- Dr. Vanderplas stated that he had not tried to employ this theory since he is not familiar with it.
- Dr. Chapanis suggested that Dr. Vanderplas contact Dr. Fred Frick who has done considerable work on information theory which might be relevant to this problem.

REPORT ON THE WORK OF THE INTERNATIONAL COMMISSION ON ILLUMINATION IN STANDARDIZING COLOR SPECIFICATIONS FOR LIGHT SIGNALS

F. C. Breckenridge
National bureau of Standards

1. BACKGROUND

At the Eleventh Session of the International Commission on Illumination (C.I.E.) in July 1948, Mr. J. G. Holmes of Great Britain presented a paper discussing the basis for the specification of signal colors and comparing the specifications in use in the several countries. This paper made it clear that there is much more variation between the specifications used in different services and in different countries than can be justified by any scientific considerations. As the result of Mr. Holmes' paper, the Commission established an international technical committee (26e) to study the problem of eliminating insignificant differences in the specifications for signal-light colors. The committee was specifically directed to consider the need for more than one specification for the same nominal colors especially in cases where non-selected observers are involved.

Technical Committee 26e circulated a questionnaire to the 18 countries which at that time were members of the C.I.E. and on the basis of the replies received transmitted a recommendation to the International Civil Aviation Organization (ICAO) that the specifications for aviation colors should consist of an envelope of three specifications for such colors; namely, those recommended by the C.I.E. in 1935 and those in current use in Great Britain and the United States. This recommendation was accompanied by a summary report of the specification limits in use in the several countries that had included such specifications in their replies to the questionnaire.

At the meeting of the Aerodromes, Air Routes, and Ground Aids Division (AGA) of ICAO in November 1949, the above recommendations were accepted in principle but the boundaries of the several colors were rectified in accordance with the principle that they should, when feasible, approximate constant hues and saturations. This resulted in the omission of some small areas of chromaticity that were not considered important by any of the countries concerned. The AGA Division also addressed a request to the C.I.E. asking that their color definitions should be studied and amendments recommended if any were found desirable.

Committee 26e then continued to collect reports on specifications for other services and prepared Secretariat Report 26e which was presented at the Twelfth Session of the C.I.E. in June 1951.

2. SECRETARIAT REPORT 26e

Secretariat Report 26e is useful for reference purposes and for this reason its contents are abstracted below under the titles used in the report. The compilations were prepared by the Secretary and the other sections were drafted by the Chairman, but unfortunately there was not sufficient time to coordinate the proposals with the other members of the committee in advance of the 12th Session.

2.1 Introduction

A summary of the committee's activities, of which the previous section of this report is a condensation.

2.2 Summary of Replies to Questionnaire.

A compilation of tables and quotations from the questionnaires. These not only report the definitions and specification practices in the several countries but also the views of their experts as to types of specifications to be internationally standardized, and the scope of each.

2.3 Comments on the ICAO Specifications.

A color by color discussion of the definitions adopted by the AGA Division from the standpoint of a dual set of definitions, one for long range, the other for higher certainty. This is followed by the chairman's recommendations for modifying the ICAO definitions for "variable yellow" and "variable white".

2.4 Proposals for Unification of International Specifications.

A discussion in broad terms of the form of specifications to be used, the applicability of long-range and high-certainty requirements to specifications in specific services, and comments on the definitions which were being proposed in the final section of the Secretariat Report.

2.5 Draft Resolutions

A collection of ten resolutions drafted by the Chairman of the committee for the consideration of the committee at its meeting in Stockholm is presented. Two of these resolutions contain sets of basic definitions for long-range and high-certainty systems of signal lights. Among the others are comments on the work of the ICAO and recommendations for the application of the two systems of definitions to the following services.

1. Aircraft lights
2. Airway lights
3. Aerodrome - general signals
4. Aerodromes - identification lights
5. Ships navigation lights
6. Lighthouse and coast lights
7. Warning lights on automobiles
8. Road traffic signals
9. Railroad crossing lights
10. Railroad signals

2.6 Appendix

Appended to the report are the following lists and tables:

1. Bibliography
2. List of referenced specifications
3. Table of specifications for signal-light colors
4. Chromaticity diagrams in C.I.E. coordinates
5. Chromaticity diagrams in R-U-C-S coordinates

3. U. S. PROPOSALS

The secretariat recommendations for most of the boundaries differed from the standards which had been adopted by the AGA Division of the ICAO. In some cases the proposed boundaries were more restricted than the ICAO boundaries and in other cases they were much more liberal. Less attention was given to the desirability of having boundaries which could be enforced by practical inspection procedure. For this reason particularly the recommendations were not entirely acceptable to U. S. practice and a set of counter-proposals designed to meet the needs of coordination in the U. S. were drafted and distributed to the C.I.E. delegates at Stockholm.

4. THEORETICAL CONSIDERATIONS*

A complete specification for the colors of signal lights involves three steps:

1. Basic definitions for colors suitable for the service intended,
2. Master specifications for limit standards to be used in testing equipment designed to give colors within basic definitions,
3. Procurement specifications for the purchase of such equipment.

The basic definitions are generally stated in the form of boundary equations in C.I.E. chromaticity coordinates. The task of such organizations as the ICAO and the International Commission on Illumination is largely to establish suitable basic definitions.

The master specifications should be so drafted that light of any color temperature to be used in service will have a color within the basic definitions after transmittal through any of the specified standard filters, or through any similar filtering material within the transmittance limits. The procurement specifications may be comparatively brief documents requiring material similar to the standard filters, intermediate between them in chromaticity, and within stipulated limits of transmittance.

It is to be noted that this method of specifying the colors of signal lights does not make every chromaticity within the basic definitions acceptable for procurement orders. It is necessary from the standpoint of inspection that the colors to be compared be comparatively similar as otherwise it is not feasible by the simple methods of color comparison available at the usual manufacturer's plant to determine whether or not the material submitted for inspection is satisfactory.

As a further aid in carrying out the inspection of signal equipment it is desirable that the boundaries between the acceptable and unacceptable material follow readily recognized lines. When feasible, it is desirable that these lines be either lines of constant hue or lines of constant saturation. When these lines are not practicable, a boundary normal to the direction of the natural variation appears a reasonable choice.

5. SESSION OF THE INTERNATIONAL COMMISSION ON ILLUMINATION, STOCKHOLM. 1951

Between June 26 and July 5, 1951, the International Commission of Illumination held its 12th Session in Stockholm, Sweden. At that Session the Committee on Color Specifications for Light Signals reviewed the ten resolutions recommended in the Secretariat report, and

*A more complete discussion of this problem will be found in the preliminary edition of "Specification of the Colors of Signal Lights", National Bureau of Standards Reference 2.1.A.1, May 1951.

~~SECRET~~

adopted nine resolutions based upon them. In general the basic definitions for signal-light colors included in these resolutions are compromises between the original draft definitions adopted by ICAO and the ones drafted by the Chairman of Committee 26e. The committee's resolutions were all approved in the final plenary session and have now been confirmed by the actions of the national committees in the several countries.

In addition to adopting resolutions containing the basic definitions, the adopted resolutions also make it clear that national agencies or others framing specifications for specific-uses may be justified in adopting more restricted boundaries than the ones contained in the C.I.E. recommendations. These resolutions also contain a reply to the inquiry addressed to the C.I.E. by the AGA Division of ICAO.

6. REPORT OF U. S. REPRESENTATIVE

Following the meeting of the C.I.E. in Stockholm, the U. S. Representative prepared a brief report describing the proceedings at Stockholm and giving the adopted resolutions. To facilitate the interpretation of the basic definitions, diagrams were included in this report showing the boundaries adopted and their relationship to current specifications for signal-light colors.

It is the purpose of such diagrams to illustrate the chromaticity relationships which are difficult to visualize unless one is a specialist, by substituting spatial relationships, which anyone can picture. If such geometrical representation is to be meaningful, it is important that it be done with a uniform chromaticity scale for the spatial relationships. The R-U-C-S diagram comes much closer to providing this uniformity in the case of signal-light colors than does the C.I.E. diagram and for this reason the diagrams which were prepared for the U. S. Representative's report were prepared in terms of the R-U-C-S coordinates. These five diagrams have been reproduced as a part of this report.

7. PRESENT STATUS

Since the meetings in Stockholm there has been no further progress internationally with the work of the Committee 26e. At the Stockholm meeting it was decided that the technical committees should be reorganized and no progress can be made with this problem until this reorganization has been carried out and the new membership of the Committee on Specification of Signal-Light Colors has been constituted.

EXPLANATORY NOTES FOR TABLES 1 AND 2

- I. C. A. O. Standards adopted by Aerodromes, Air Routes, and Ground Aids Division of International Civil Aviation Organization, Doc. 6932 - AGA/590, Dec. 1949; Part IV, Sec. 5.2.2, pp. 55-57.
- I. C. A. O. rp As above, recommended practice.
- I. C. A. O. Var. As above, for yellow and white lights with sources of variable color temperature.
- New New definition proposed at Stockholm session of C. I. E.
- Prop. C Proposal C of Secretariat Report for C. I. E. Technical Committee 26e.
- Prop. R Proposal R of Secretariat Report for C. I. E. Technical Committee 26e.
- U. S. Prop. Proposals prepared by U. S. Representative, C. I. E. Technical Committee 26e, dated June 15, 1951.
-

SPECIFICATIONS SHOWN IN THE FIGURES

- G General purpose colors; International Commission on Illumination, 12th Session, Stockholm, 1951.
- H Higher certainty colors; International Commission on Illumination, 12th Session, Stockholm, 1951
- I International Civil Aviation Organization; "Final Report Aerodromes, Air Routes, and Ground Aids Division, Fourth Session", Doc. 6932-AGA/590, Dec. 1949; Part IV, Sec. 5.2, pp 55-57; including recommended practice and "variable" colors.
- F Federal Standard No. 3; U.S. General Services Administration; "Colors, Aeronautical Lighting"
- L Lighthouse Service, U.S.; "Army-Navy Aeronautical Specification, Colors; Aeronautical Lights and Lighting Equipment", 1945; Sec D, p 2 and Amendment 3.
- A Automotive vehical lights; Society of Automotive Engineers, U.S., Standard, "Color Specification for Electric Lamps".
- T Traffic signals; American Standards Association, Standard D 10.1, 1942, "Adjustable Face Traffic Control Signal Head Standards"; Part A, Sec 5-7, p 7.
- X R R crossing signals; Association of American Railroads, Signal Section Specification 69-48, "Signal Glasses, (Exclusive of Kerosene Hand Lantern Globes)", 1949; Part A, Sec 5, p 3, Type 4.
- E Electric and other signals; Association of American Railroads, Signal Section Specification 69-48, "Signal Glasses, (Exclusive of Kerosene Hand Lantern Globes)", 1949; Part A, Sec 5-10, p. 3, Types 1, 2, and 3.
- K Kerosene lanterns; Association of American Railroads, Signal Section Specification 59-39, "Kerosene Hand Lantern Globes", 1939; Part A, Sec 5-8, p 3.

TABLE 1

Chromaticity Boundaries for Signal Lights - General Set
Recommendations of the International Commission on Illumination

Technical Committee 26e

<u>Color</u>	<u>Boundary</u>	<u>C. I. E. Equation</u>	<u>Source*</u>	<u>R-U-C-S Equation*</u>
Red	Yellow	$y = 0.335$	I. C. A. O.	$y'' = - 0.317$
	Purple	$x + y = 0.980$	Prop. R	$x'' = + 0.070$
Yellow ^o	Red	$y = 0.382$	New	$y'' = - 0.225$
	Green	$x = 0.454 + 0.240 y$	New	$x'' = + 0.603 y'' + 0.155$
	White	$y = 0.790 - 0.667 x$	Prop. R	$x'' = + 0.063 - 0.050 y''$
	(and)	$x = 0.698 - 0.333 y$	New	$x'' = + 0.093 + 0.158 y''$
Green	Yellow	$x = 0.333$	New	$x'' = 0.872 y''$
	Blue	$y = 0.390 - 0.171 x$	I. C. A. O.	$x'' = - 0.150 y''$
	White	$x = 0.650 y$	U. S. Prop.	$y'' = + 0.085 - 0.584 x''$
Blue	Green	$y = 0.065 + 0.805 x$	U. S. Prop.	$x'' = - 0.942 y''$
	Violet	$x = 0.133 + 0.600 y$	I. C. A. O. rp	$y'' = - 0.205 x''$
	White	$x = 0.480 - y$	I. C. A. O.	$x'' = - 0.075 + 0.250 y''$
White	Yellow	$x = 0.560$	I. C. A. O. Var.	$x'' = + 0.115 + 0.300 y''$
	Blue	$x = 0.310$	New	$x'' = - 0.025 + 0.984 y''$
	Green	$y = 0.150 + 0.640 x$	I. C. A. O.	$x'' = + 0.020 - 0.700 y''$
	(and)	$y = 0.640 - 0.400 x$	I. C. A. O. Var.	$x'' = + 0.055 - 0.100 y''$
	Purple	$y = 0.050 + 0.750 x$	I. C. A. O.	$x'' = - 0.026 - 0.900 y''$
	(or)	$y = 0.390$	Prop. R	$x'' = + 0.024 - 0.240 y''$

*Not in original text. See explanatory notes for specifications of origin.

^oSee note following Table 2.

TABLE 2

Chromaticity Boundaries for Signal Lights - Higher Certainty Set
Recommendations of the International Commission on Illumination

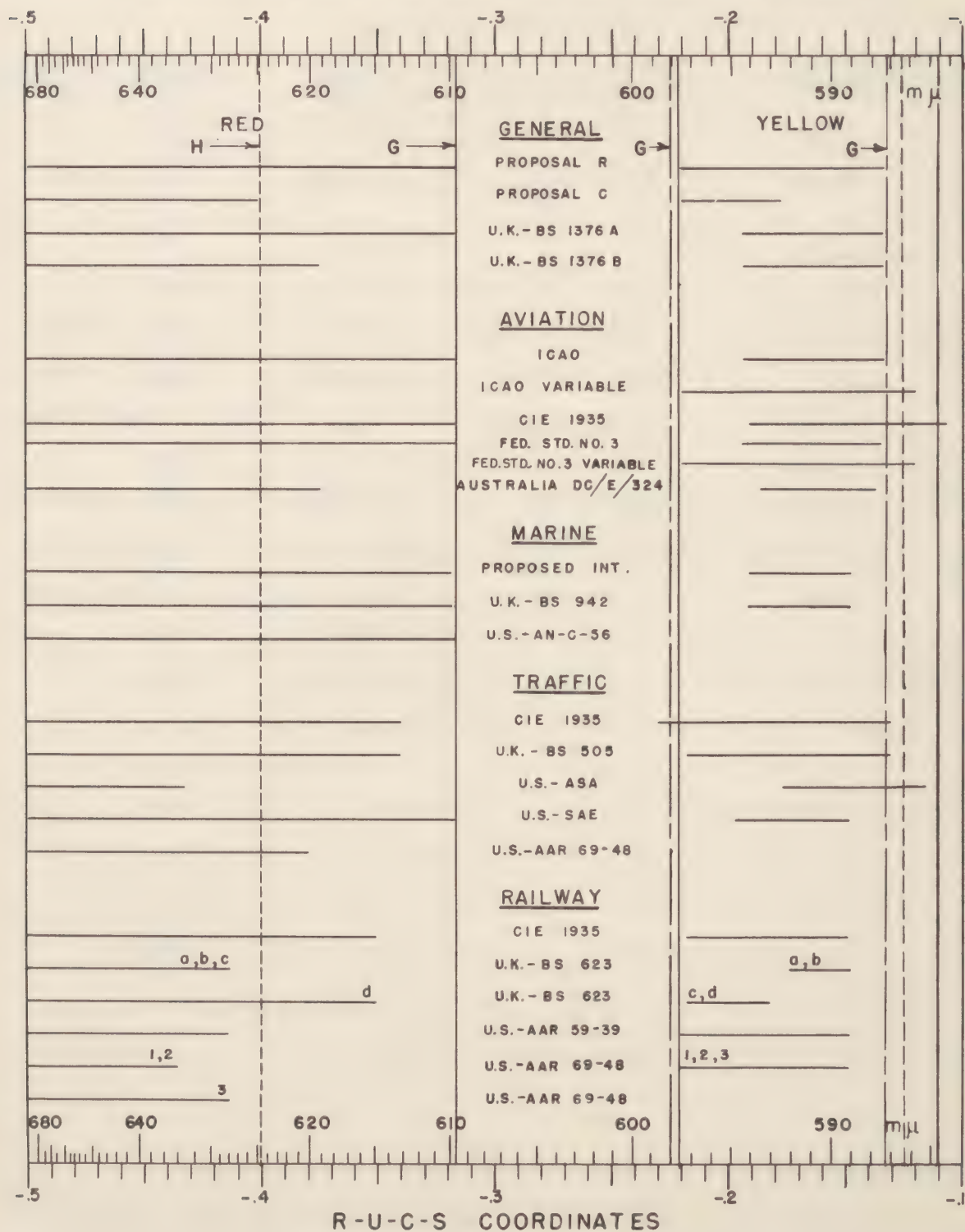
Technical Committee 26e

<u>Color</u>	<u>Boundary</u>	<u>C. I. E. Equation</u>	<u>Source*</u>	<u>R-U-C-S Equation*</u>
Red	Yellow	$y = 0.300$	Prop. C	$y'' = - 0.401$
	Purple	$x + y = 0.985$	I. C. A. O.	$x'' = + 0.071$
Yellow Reserved for Study.				
Green	Yellow	$x = 0.500 - 0.500 y$	New	$x'' = + 0.310 y''$
	Blue	$y = 0.390 - 0.171 x$	I. C. A. O.	$x'' = - 0.150 y''$
	White	$x = - 0.030 + 0.650 y$	New	$y'' = + 0.104 - 0.650 x''$
Blue	Green	$y = 0.065 + 0.805 x$	U. S. Prop.	$x'' = - 0.942 y''$
	Violet	$x = 0.133 + 0.600 y$	I. C. A. O. rp	$y'' = - 0.205 x''$
	White	$x = 0.400 - y$	I. C. A. O. rp	$x'' = - 0.125 + 0.350 y''$

White Reserved for Study.

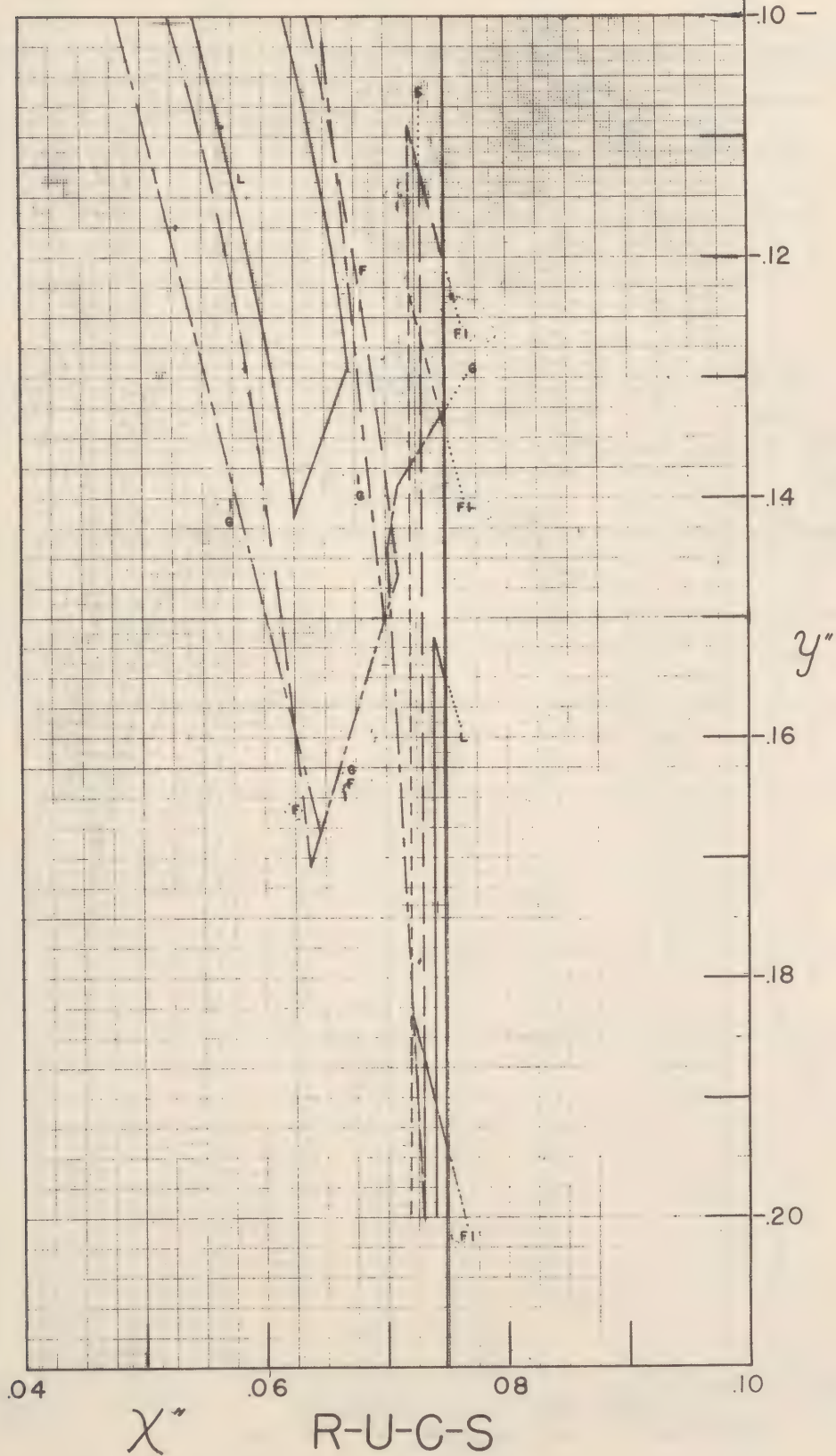
*Not in original text. See explanatory notes for specifications of origin.

^oWhile the limiting boundaries defined in these recommendations should not be exceeded unless there is valid reason for doing so, when a yellow signal is shown in combination with another color, it may be possible to exceed these limits somewhat without undue risk of confusion.

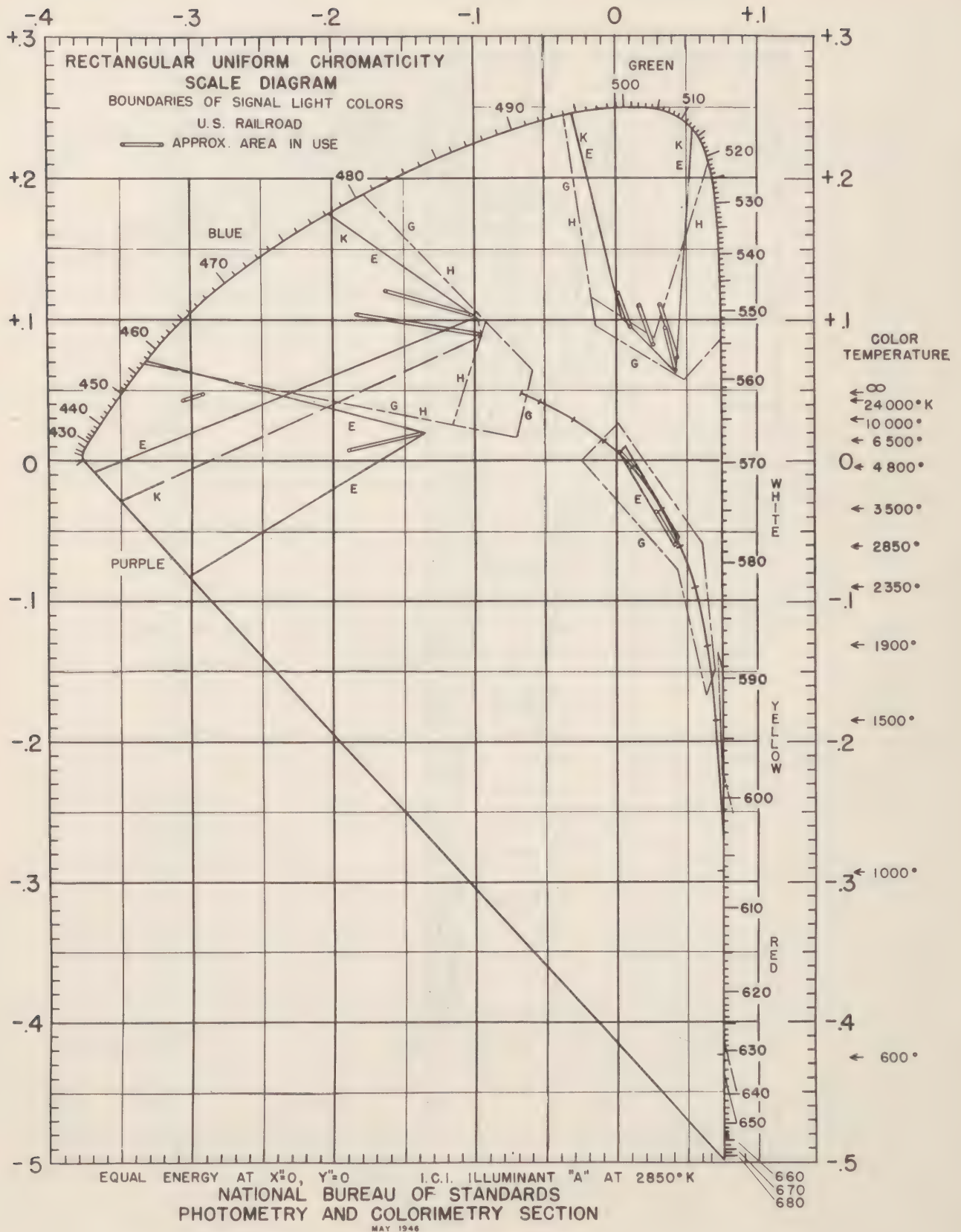
COMPARISON OF RED AND YELLOW SPECIFICATIONS^v

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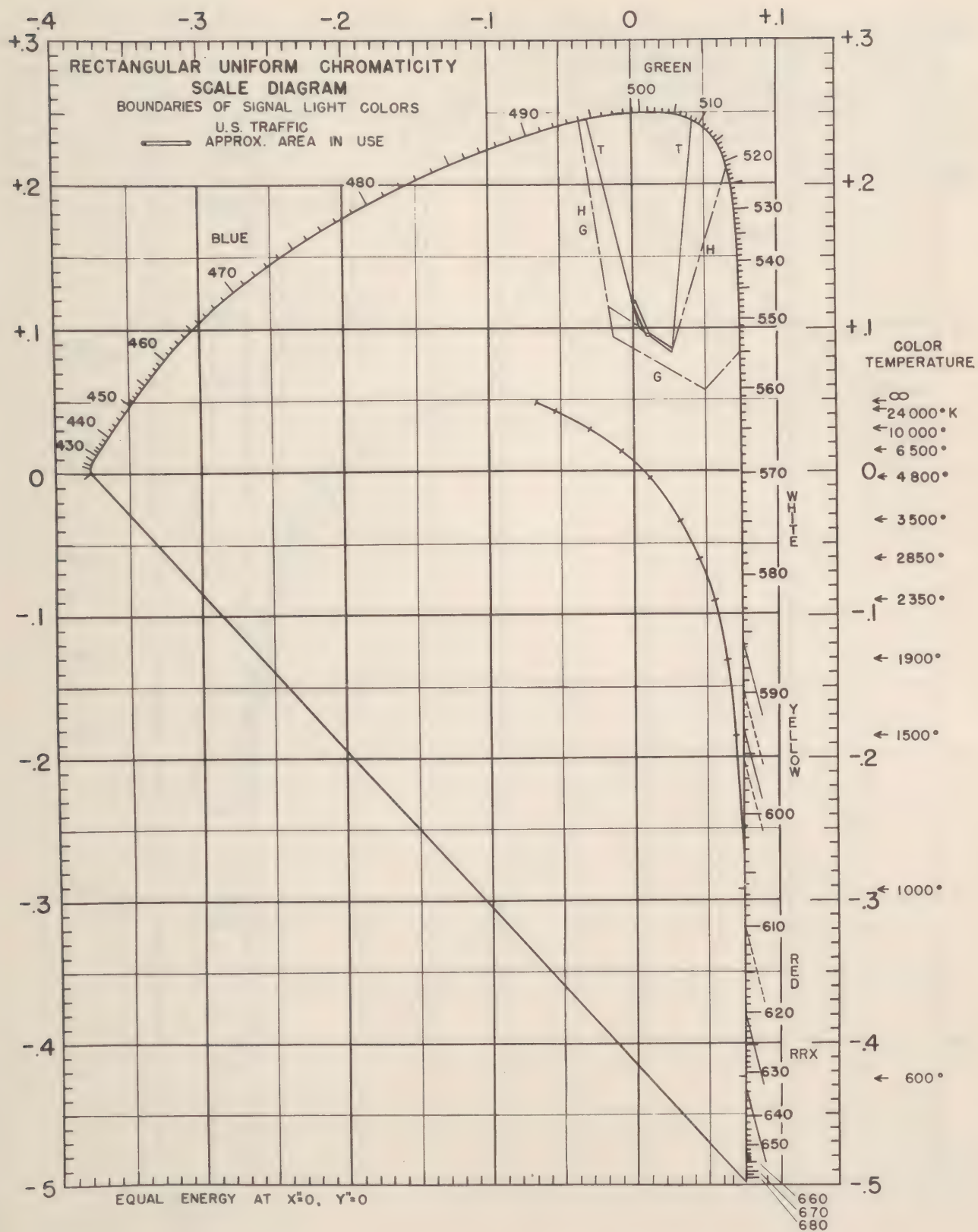
BOUNDARIES IN YELLOW-WHITE REGION

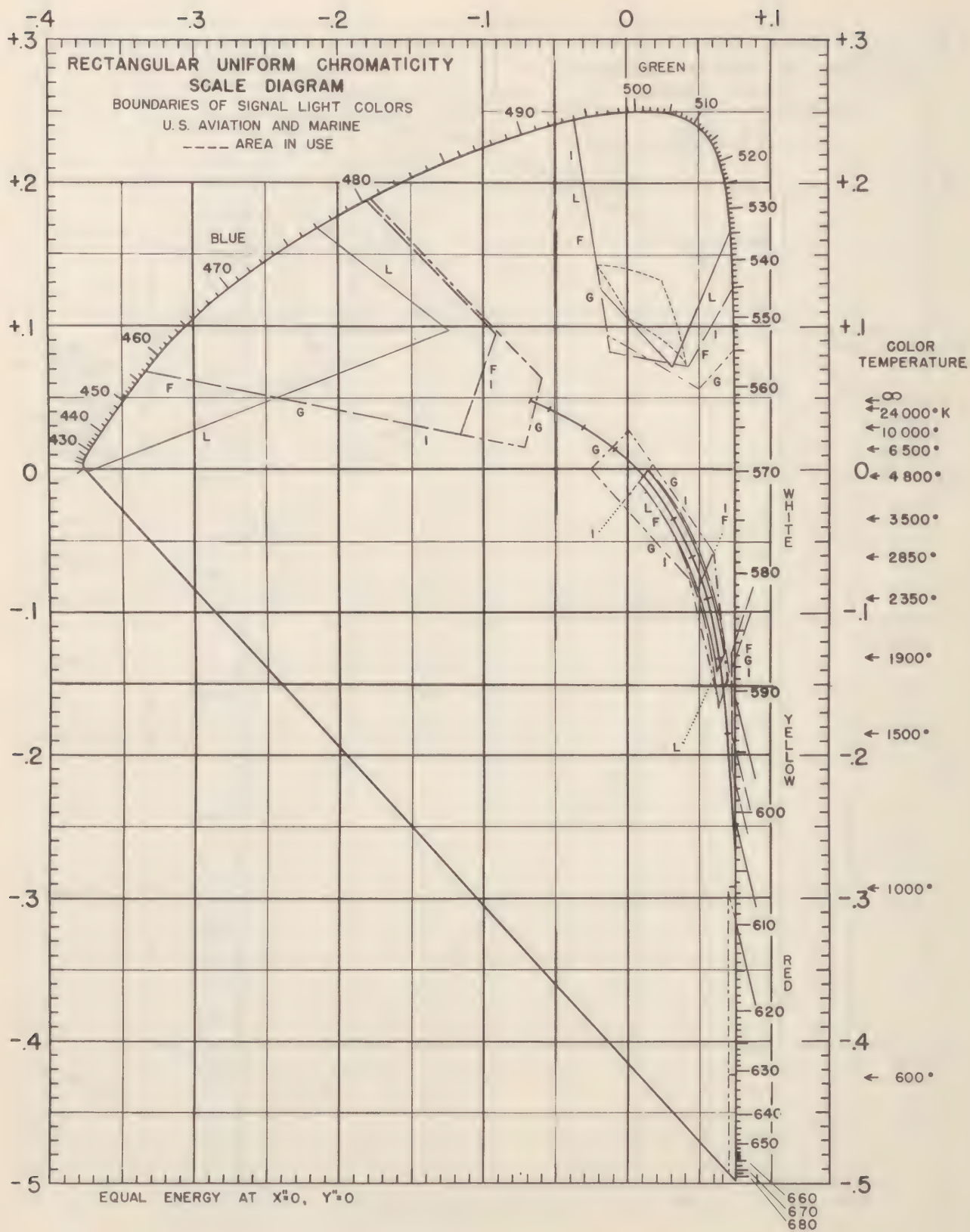


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Author's Note

In this country, the study of the problem of bringing the specifications of the different services into a more harmonious relationship has continued to receive study. An omnibus specification has been prepared which provides for two sets of basic definitions, one for aviation and marine applications and the other for land transportation. When this specification and an explanatory text has been completed, it will be circulated to the various U. S. agencies responsible for the specifications used for signal-light colors for comment. In the meantime, the ICAO standards have been reviewed in the light of the C.I.E. recommendations and the omnibus specification and the U. S. position with reference to changes in the ICAO standards is now being formulated.

STANDARD COLOR FILTERS FOR ELECTRONICS EQUIPMENT

by Deane B. Judd

Chairman, Working Group on Standard Color Filters
Armed Forces - National Research Council Vision CommitteeI. Introduction

The request for a selection of color filters for standard use on electronic equipment came from Dr. John F. Corso, Chief of the Displays Section of the Human Factors Office, Griffiss Air Force Base, Rome, New York. The problem may be stated as follows:

Signal lights are employed on the control panels of electronic communications equipment and maintenance and testing apparatus. These signal lights are normally produced by "jewels" placed over either incandescent sources or neon lamps. The signal lights may inform the operator on such general questions as whether the equipment is in stand-by readiness, interlocks are closed, tube cooling is working, etc.; but in addition, for some apparatus the signals indicate specific features about the equipment. For example, channel selection, malfunction of specific components, and antenna selection may be indicated by the color and location of a light signal.

Since the "jewels", which are simply color filters, are used with incandescent sources of varying color temperature and with neon lamps as well, there is at present a considerable range of colored signals employed which are nominally the same color. Furthermore, the "jewels" vary in size and vary in the distance at which the operator views them so that the visual angle subtended by the colored signals varies considerably.

The Air Force would like to have three or four color filters which could be quickly and surely recognized by normal and color defective observers under a maximum number of conditions of illumination and viewing distance. The Air Force would presumably be willing to eliminate the use of neon lamps if this was necessary in order to have satisfactory color filters. The Air Force would also like to have specified the minimum visual angle which a jewel may subtend and still be satisfactorily recognized. This information could be converted into information on jewel size from knowledge of the distance at which the pieces of equipment are viewed.

It is requested that these filters should be chosen after due consideration of the problem of manufacture and supply. Thus the materials utilized should lend themselves to moulding or machining and should not be in short or critical supply.

The present report attempts to provide specifications for standard color filters applicable to the stated problem and to indicate the basis for the specifications.

II. Basis for the Recommended Standard Filters

The selection of colors for signaling at ranges, such as for electronic equipment, measured in inches, is a simplified case of the much more difficult problem of signaling at ranges, such as for highway, railway, marine, and aviation traffic signaling, measured in yards, and at times in miles. This latter problem has received intensive theoretical, laboratory, and field studies during the last 30 years. These studies have included the influence of intensity and angular subtense of the signal light, and color blindness and adaptation

of the observer. Since the problem of signaling by colored lights over distances measured in yards has been solved, there is no need for further studies to supply basic data for the simpler problem of doing the same thing over the much smaller distances measured in inches. Signal lights conforming to the requirements of aviation red and aviation green as defined in Army-Navy Aeronautical Specification, AN-C-56, "Colors; Aeronautical Lights and Lighting Equipment" assure recognizability at considerable distances by red-green confusers and observers of normal vision alike. Aviation blue of the same specification (AN-C-56) is satisfactorily distinct from red and green at moderate distances. The three colors satisfy these requirements all the more certainly at the short ranges over which the condition of electronic equipment must be made evident. There remains only to summarize the steps that led to these choices of colors so that the logic of the choices will be apparent and the temptation to substitute colors not conforming to the requirement of Aviation red, green, and blue will be removed.

III. Fundamental Distinction between Normal Color Vision and Dichromatic Vision

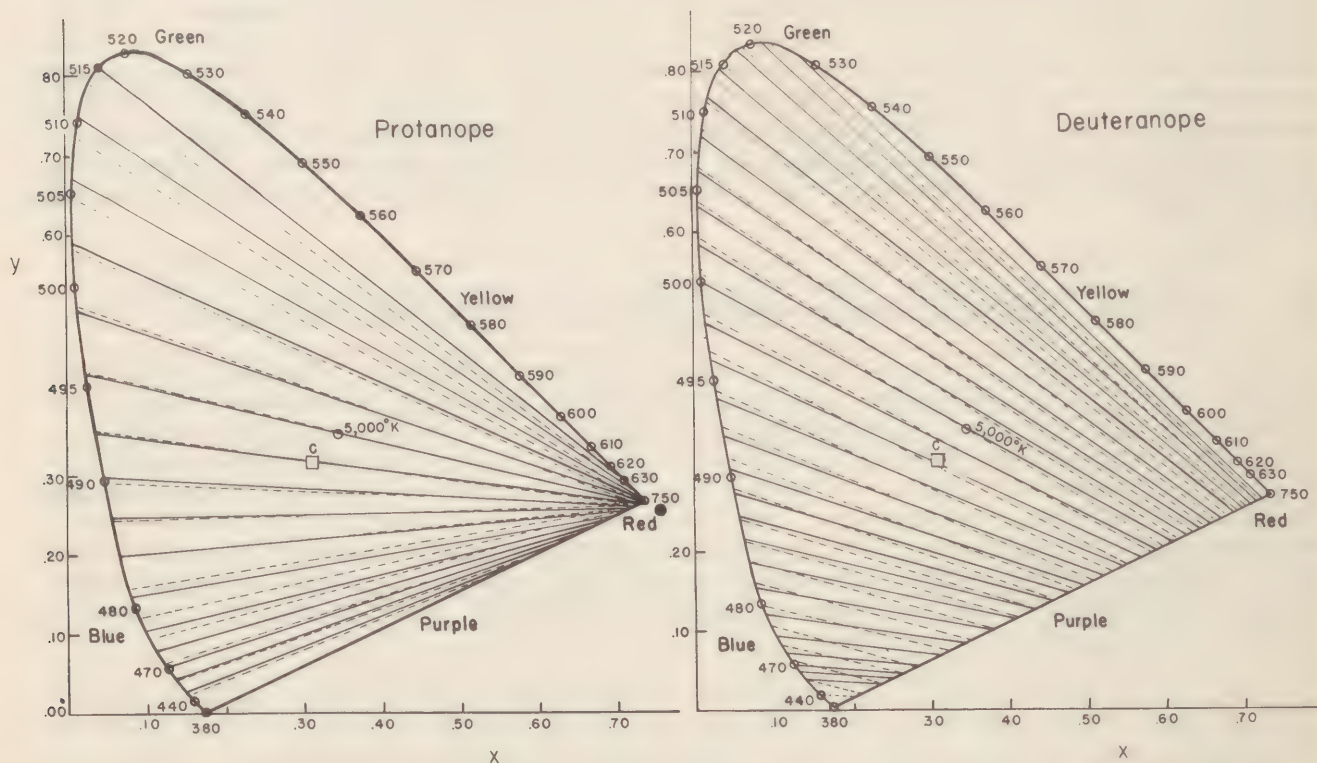
For the observer of normal vision, color has three dimensions. For the specification of signal lights, these dimensions may be broken down into the two-dimensional quantity, chromaticity, and the appropriate photometric quantity, luminous intensity (for sources so distant as to appear as points) or luminance (for sources subtending appreciable angles at the eye of the observer). Since no different meaning is to be attached to a brightly lit jewel as distinguished from a dimly lit one, the distinctions to be conveyed by the signals must rest upon chromaticity alone. For the observer of normal vision, chromaticity may vary in two dimensions, yellow to blue, and red to green; and it would be feasible to choose eight or nine extended-field chromaticities immediately recognizable under laboratory conditions by an observer of normal color vision.

There are two forms of color defectives of sufficiently common occurrence to deserve consideration. These are the types referred to as protans and deutans by Cmdr. Dean Farnsworth. Observers of both of these types tend to confuse red with green. About 6% of the male population have a significantly reduced ability to distinguish red-green differences; and for an additional 2%, called dichromats, this ability is to all intents and purposes zero. Figure 1 shows in detail the chromaticities confused by the two types of dichromat, protanopes and deuteranopes. The chromaticities defined in the (x, y) - chromaticity diagram of the CIE system by each straight line shown are indistinguishable to dichromatic observers of the indicated type provided their ocular media (lens, macula) are normally pigmented.¹ It is evident that dichromatic chromaticity is a one-dimensional quantity. Protanopes and deuteranopes perceive colors of but two hues, blue and yellow.²

IV. Choice of Signal Colors Distinguishable by Protans and Deutans

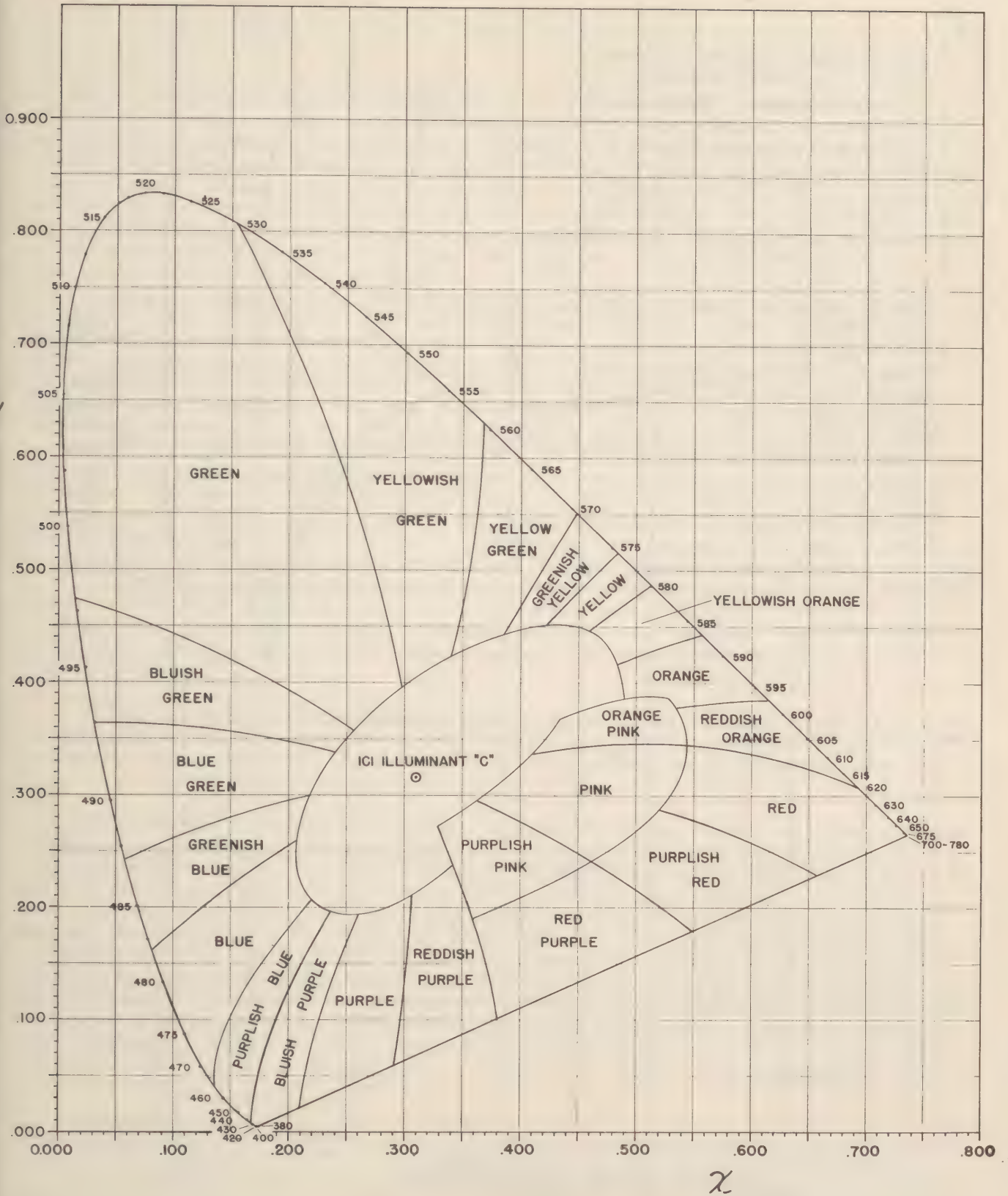
Figure 2 shows the color names given by daylight adapted observers of normal vision to lights of chromaticities of various parts of the (x, y) chromaticity diagram.³ There is a fairly extensive central area denoting lights insufficiently different from daylight to be perceived as having a distinctive hue. No name is given to this area. From Figures 1 and 2 it may be seen that red-green confusers perceive as blue a group of colors that for observers of normal color vision range from greenish blue to purple. They perceive as neutral a group of colors ranging for normal vision from bluish green to purplish red. And they perceive as yellow the color range normally said to extend from green through yellow to red. Aviation blue appears blue to normal and red-green confusing vision alike. The bluish part of the chromaticity range basically defined as aviation green appears neutral to red-green confusers, and aviation red appears yellow to them. They are quite accustomed, however, to give to a light perceived by them as yellow the name, red, particularly if they are told that the signal system has in it only the three chromaticities correctly named for normal

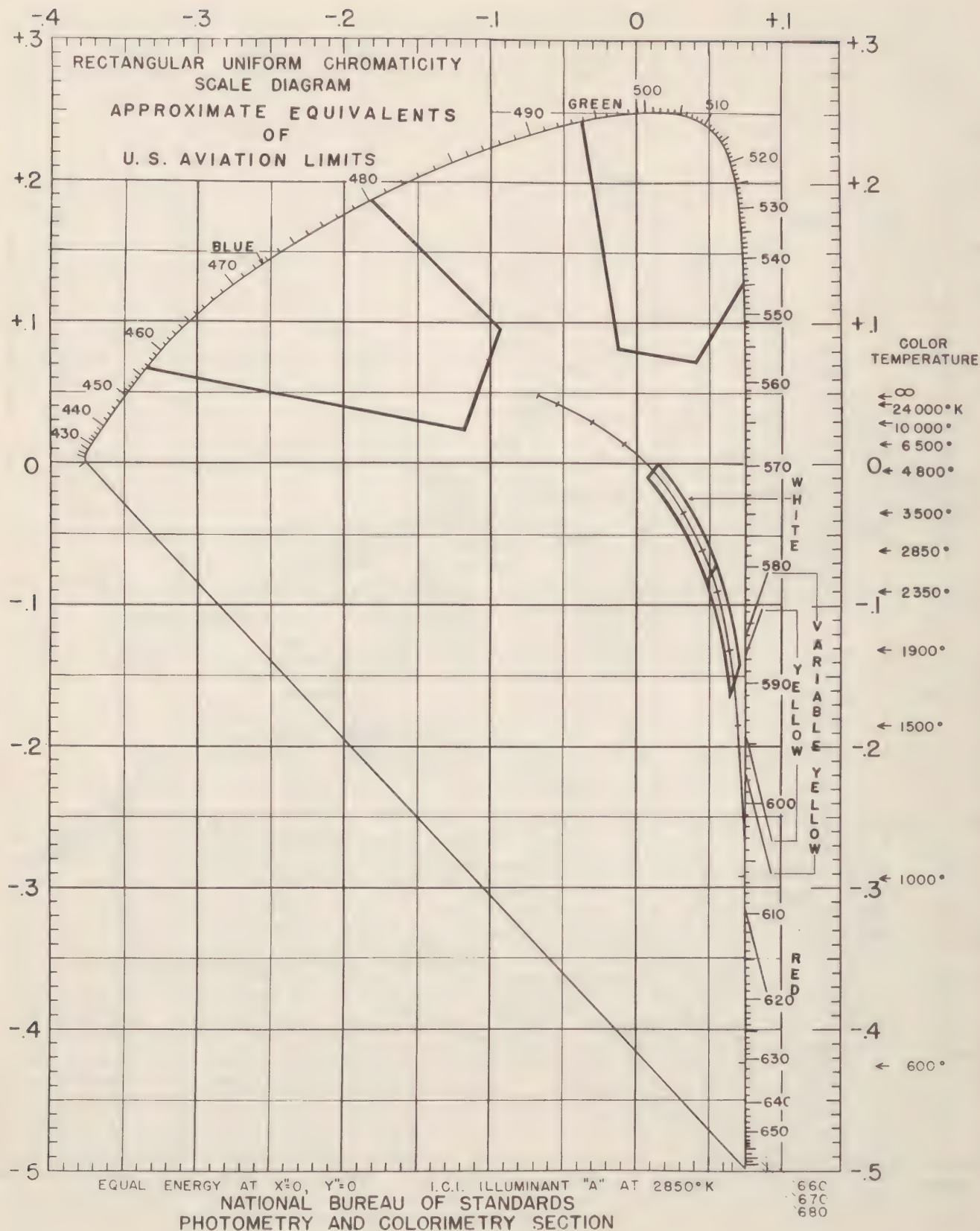
vision, blue, green, and red. They have been doing this kind of color naming all their lives. Aviation red, green, and blue thus make a satisfactory choice of three colors distinguishable alike by observers of normal color vision and by red-green confusers (protans and deutans).



Chromaticity Confusions of the Protanope and Deuteranope - after Pitt

Let us now consider what is involved if we have to squeeze a fourth color into the system. The red-green confuser might possibly respond adequately to a five-color system perceived by him as saturated blue, pale blue, neutral, pale yellow, saturated yellow. The color, pale yellow, corresponds for the red-green confuser, as well as for the observer of normal color vision, to the color of the bare incandescent lamp at rated voltage and is presumably undesirable as a signal color because of the likelihood that many other lights of this color will be visible on occasion that have no signaling significance. We might still think of expanding the signal system to a four-color system by substituting for aviation blue two colors to be perceived by the red-green confuser as pale blue and saturated blue, but this expansion brings us into a new difficulty. There is danger that the pale blue will be confused with aviation green (neutral to the red-green confusers), and saturated blue might cause trouble from the very low luminous transmittance of the blue filter required to produce saturated blue from incandescent-lamp light. This trouble might take the form of insufficient luminance, high power consumption, fading or softening of plastic filters from overheating, or cracking of glass filters from overheating. The names that have to be assigned (such as pale blue and deep blue) are rather confusing. It is recommended, therefore, that the signal system be restricted to three colors: aviation red, aviation green, and aviation blue. Neon red can be used in this system; it satisfies the requirements for aviation red. Plastics to produce these three colors by combination with incandescent lamps were available during World War II, and can certainly be made available again. Glasses to produce these three colors are currently available. There should be no unusual moulding, machining, or procurement problems.





V. Effect of Reducing Color Temperature of Incandescent Source

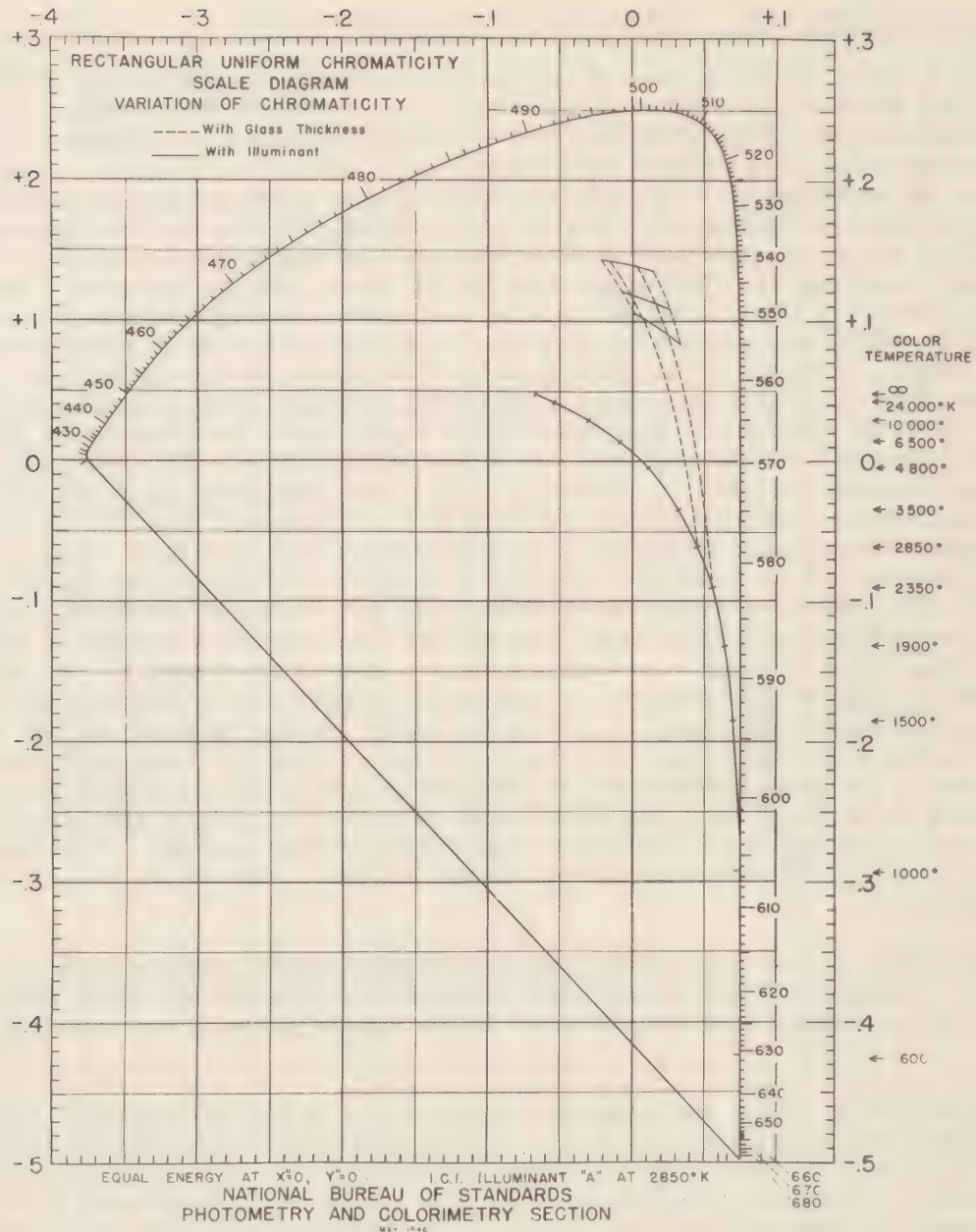
Figure 3 shows the boundaries of the basic chromaticity definitions of aviation blue, green, and red according to Federal Standard No. 3, (21 March 1951), Colors, Aeronautical Lighting, expressed on the RUCS projection⁴ of the CIE chromaticity diagram. On this diagram the chromaticity confusions of the deuteranope correspond closely to vertical lines, and those of the protanope to straight lines copunctal at a point just beyond the long-wave extreme of the spectrum (about $x'' = 0.075$, $y'' = -0.54$). It may be seen that any chromaticity satisfying the requirements of aviation blue will be distinguishable from all chromaticities satisfying the requirements of either aviation red or green even by red-green confusers, but the yellower portion of the aviation green area on the chromaticity diagram is confusable with aviation red by red-green confusers. Why then is it true that aviation green glassware supplied in accordance with AN-C-56 yields signals in the bluer portion of the basic aviation green chromaticity range and so gives a signal distinguishable from aviation red by red-green confusers? This successful use of aviation green signal lights procured under specification AN-C-56 is explained by other requirements of that specification. The minimum transmittance requirements exclude a considerable part of the confusable area, the rest is excluded by requirements stemming from the need to have glassware that will yield signals within the basic chromaticity limits for a considerable color-temperature range of the source. These requirements are not stated in AN-C-56 directly for the glassware, itself, but take the form of requirements on the pairs of filters used for standards combined with the requirement that the glassware must have chromaticity characteristics similar to those of the standards. The effect of these requirements may be seen from Figure 4. In this figure the variations in chromaticity produced by variations in thickness or colorant density of aviation green glassware are shown by the dotted lines, and the variation in this direction is fixed by the pale-limit and blue-limit standard filters. The full lines represent variations due to changes in the color temperature of the source, and these are restricted to the ranges stated in Table III of AN-C-56. The dotted lines have their origins at the points of the Planckian locus corresponding to the color temperatures of the sources. The total variation shown in the figure corresponds to sources ranging in color temperature from 3,000 °K down to 2,100 °K.

So long as the jewels are confined to glass meeting all the requirements of AN-C-56 and are used with light sources having color temperatures between the above limits neither protans nor deutans should have any difficulty in distinguishing the green signals from the red.

If special plastic filters are developed, however, or if the transmittance requirements of AN-C-56 are relaxed in procuring glassware, chromaticities conforming to the basic chromaticity definition of aviation green might be produced that are so yellow as to be confused by protans and deutans with aviation red. To prevent the procurement of such jewels, it is necessary to supplement the basic chromaticity definition of aviation green by the additional requirement that y be not greater than $0.667(1 - x)$. This additional requirement prevents source-filter combinations falling in the objectionably yellow portion of the basic chromaticity range from being classed as acceptable. Reduction of the luminance of the signal by means of a rheostat in the lamp circuit must be avoided if the color temperature of the source is thereby reduced below the minimum color temperature for which the lamp-filter combination complies with this supplementary requirement that y be not greater than $0.667(1 - x)$.

VI. Working Standard Filters

The requirements just listed formally assure that the red, green, and blue signal lights will be quickly distinguishable by observers of normal color vision and by red-green confusers



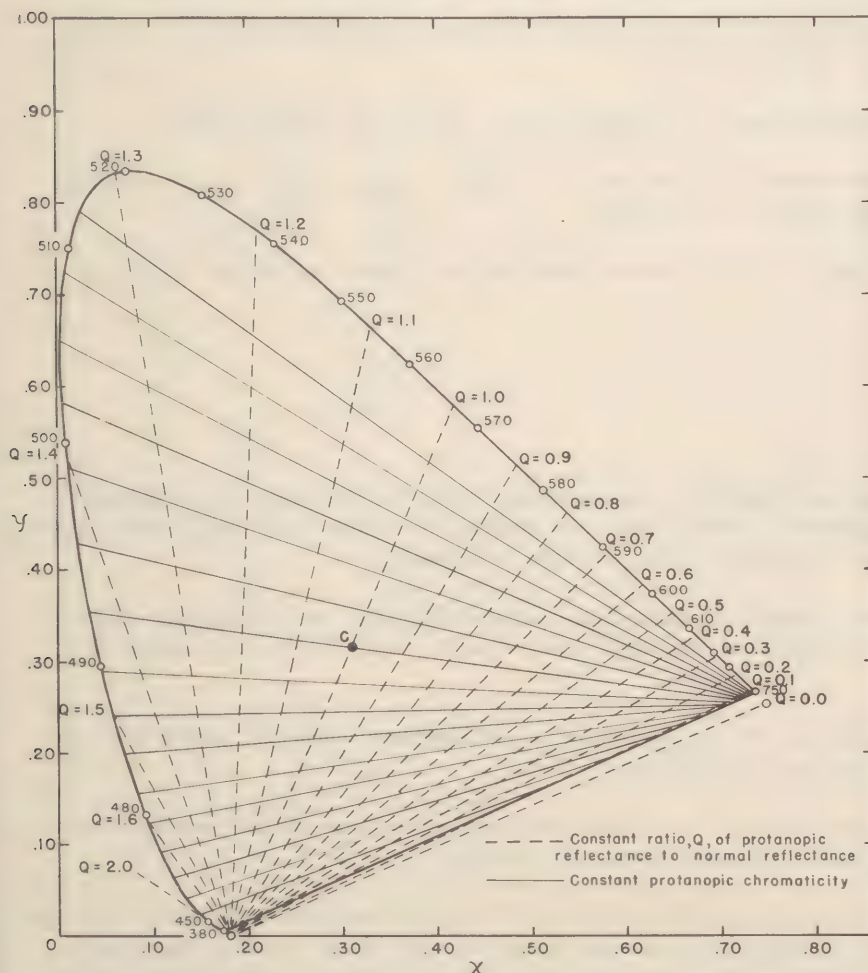
alike. The practical matter of inspecting glass and plastic jewels for conformity to these basic chromaticity definitions has still to be considered. For glass jewels the problems have largely been solved. Working standard filters duplicating any of those listed in Table III of Federal Standard No. 3 for aviation red, green, and blue are applicable to glassware of similar chromaticity characteristics for the color-temperature ranges indicated there. Duplicates of most of these filters have been certified and are in use for inspection of lighting equipment purchased by the Department of Defense and by the Civil Aeronautics Administration.

If it be desired to obtain plastic filters for use as jewels for signaling on electronic equipment, suitable working standards for use by the inspector will have to be developed. Though there are possible alternatives, the safest method is to use working standards having chromaticity characteristics similar to those of the plastic filters to be inspected on any

order. In all probability these working standards will have to be made of the same plastic materials as the jewels, themselves. Such plastic filters can be used as working standards only after spectrophotometric, or other colorimetric, studies have shown that for the color-temperature range of the incandescent-lamp sources they yield chromaticities conforming not only to the basic chromaticity definitions of aviation red, green, and blue, respectively, but also for aviation green to the supplementary requirement that y be not greater than 0.667 ($1 - x$). Since the permanence of plastic filters is generally inferior to that of glass filters, these colorimetric checks of working standards made of plastic material should be repeated at frequent intervals. Periodic reinspection of glass filters in use has been found to be unnecessary, but until each separate plastic-dye combination has been proved to be sufficiently permanent such reinspection of plastic filters cannot safely be dispensed with.

VII. Influence of Angular Size

It is known that reduction of the angular subtense of a light signal below 20' of arc renders it likely that the observer of normal color vision will make mistakes characteristic of a third form of dichromatic vision known as tritanopia.^{5,6,7} The dotted lines on Figure 5 indicate the chromaticity confusions characteristic of tritanopia. Each of these lines also incidentally indicates the locus of chromaticities for which the ratio of protanopic luminous reflectance to normal luminous reflectance is a constant, but this need not concern us here. Note, however, that many of the chromaticities qualifying as aviation blue would be confused in smaller angular subtense with some range of chromaticities qualifying as Aviation green,



though to a considerable extent increase in luminance can compensate in this respect for decreased angular subtense. For red-green confusers a small angular subtense would render all three signals (red, green and blue) indistinguishable. It is recommended that the jewels be so designed as to subtend at least 1° of arc at the eye of the observer. If this is not practical in all cases, about the same distinguishability will be achieved by increasing the luminance of the jewel by the square of the factor by which the angular subtense of the field must be reduced below 1°, thus keeping constant the density of luminous flux incident on the eye of the observer from the jewel.

VIII. Summary

It is recommended that signal lights employed on the control panels of electronic communications equipment

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be confined to three colors: red, green, and blue, and that these colors be chosen so as to conform to the basic definitions of aviation red, aviation green, and aviation blue, respectively, of Federal Standard No. 3, Colors, Aeronautical Lighting, with the supplementary requirement for the green color that its chromaticity coordinates (x,y) meet the condition: y not greater than 0.667 (1 - x). Working standards of chromaticity are available for commonly available types of glass to produce these colors by combination with incandescent-lamp light; but suitable working standards for plastic jewels have yet to be developed.

If the signal subtends 1° or more at the eye of the observer, so-called "small-field tritanopia" will be avoided; otherwise some confusion between blue and green signals of low luminance may occur.

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Discussion:

Dr. Sloan commented that protans and deutans can operate effectively if they are limited to seeing red, green and blue colors. When they are asked to call a color by some other name, such as amber, white, and blue, they become confused.

Dr. Rose stated his liking for Dr. Judd's system and commented that he is himself color defective. Dr. Rose further suggested that the Judd system would be very useful for traffic signals.

Group Capt. McCulloch commented that he is color blind and agrees with Dr. Judd that the colors selected are the only ones he could see.

Group Capt. McCulloch also commented that he does not believe a color-blind person worries as much about color names as Dr. Sloan seems to believe.

Col. Byrnes stated his belief that the Judd paper has far reaching implications as far as the Air Force is concerned. The Air Force has had trouble with color testing for years. If such a system as Dr. Judd proposes were adopted, the Air Force could cease color vision testing, and save a tremendous amount of time and effort.

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- Col. Byrnes stated that he should think the submarine service would have the same point of view.
- Lt. Comdr. Farnsworth commented that the Navy is attempting to eliminate the necessity for color cues throughout a submarine. When this program is complete, it will be possible to eliminate color vision testing from the medical examination for submarine personnel.
- Mr. Page stated his appreciation to Dr. Judd for preparing the report on color filters and expressed his belief that the report would be very useful to the Air Force.
- Dr. Chapanis expressed his concern with the selection of filters for red and green. The aviation red and green appear to be too close together, judging from the color confusion lines, which represent just noticeable differences. The envelope permitted in specifying aviation green would put some of the greens in iso-color zones with red.
- Dr. Judd agreed that it might be desirable to place more severe restrictions on specifications of the red and green filters in terms of the Z chromaticity coordinate.
- Col. Byrnes called for a motion that the Judd report be formally accepted by the Vision Committee for transmittal to the Air Force. The Vision Committee voted acceptance of the Judd report.

SUMMARY OF THE DISCUSSION
CONCERNING THE DESIRABILITY OF THE ADOPTION OF THE NIT
AS THE UNIT OF SUMINANCE

Mr. Middleton described the action of the International Commission on Illumination in recommending the international adoption of the nit as the standard unit of luminance. The nit is defined as a candle/meter². Mr. Middleton admitted that the word "nit" has an unpleasant sound to English-speaking people but defended its use on the grounds that it has no such unpleasant sound in other languages than English, and on the grounds that nit has an entirely suitable Greek root. Mr. Middleton particularly approved the idea of adopting a metric unit of luminance.

Dr. Fry stated that in his opinion there should be two units of luminance, one a candle/unit area unit and the other a Lambert type unit. The Lambert type unit is particularly useful to illuminating engineers whereas the candle/unit area unit is more likely to be useful to physicists.

Dr. Rose stated that in his opinion it would be very desirable to reduce the total number of units of luminance. The number of units of luminance now in use is appalling.

Dr. Sloan commented on the relative advantages and disadvantages of the Lambert type unit and the candle/unit area unit and expressed her personal preference for the Lambert type unit.

Dr. Hulburt suggested that the question of adoption of a standard unit of luminance falls outside the province of the Vision Committee. Dr. Hulburt proposed that a committee be set up to keep the Vision Committee acquainted with problems arising in connection with units of light.

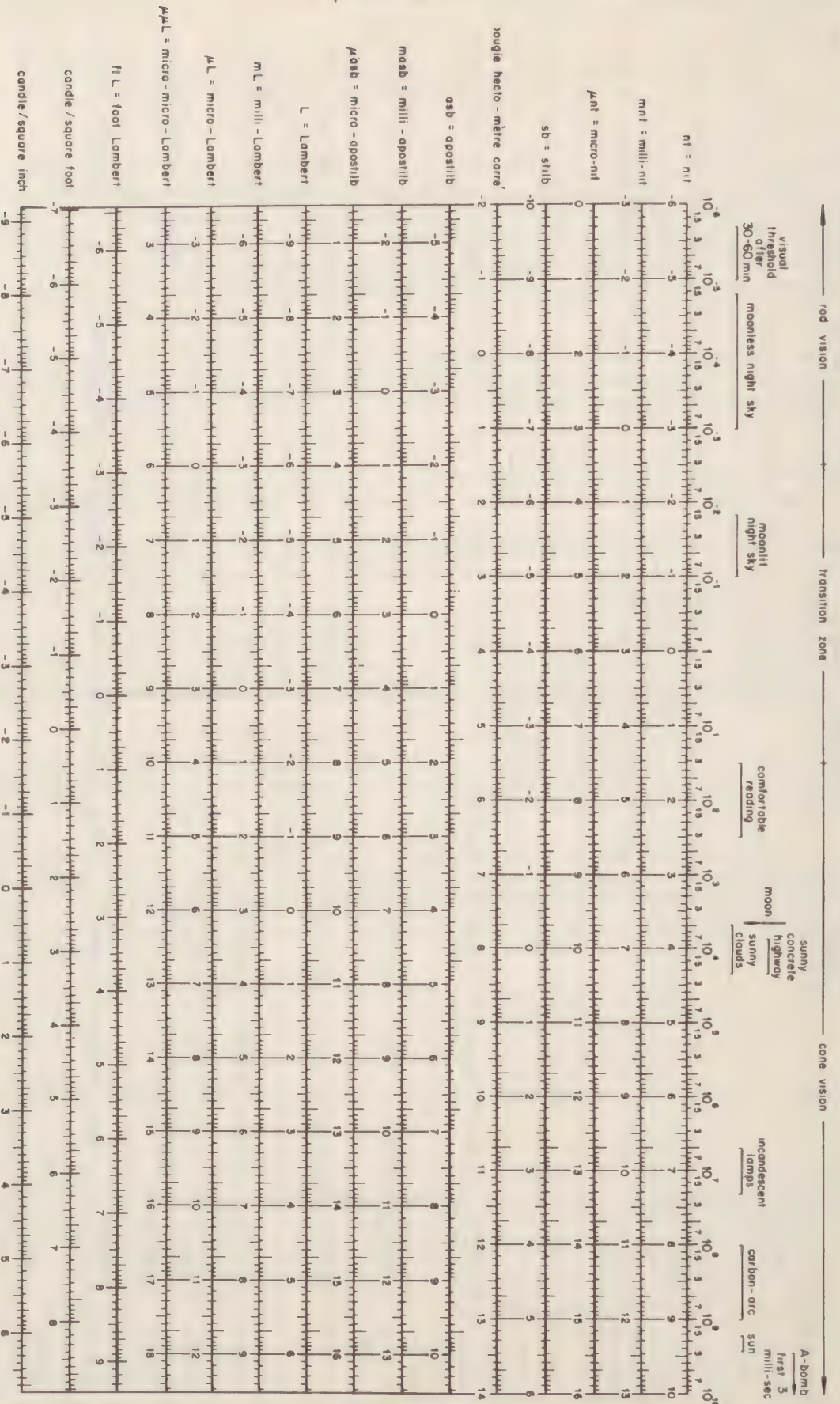
Lt. Commander Farnsworth stated that such a committee should take care not to forget the interests of the illuminating engineer, which are quite different from the interests of the physicist and vision researcher.

It was the consensus of opinion that it would not be appropriate for the Vision Committee to take any action with respect to recommending the adoption of the nit as a standard unit for luminance. It was the consensus further that the Vision Committee should be kept informed of the actions in this connection of other groups, such as the Optical Society and the Illuminating Engineering Society.

CONVERSION TABLE - UNITS OF LUMINANCE

1 Nit (nt)	$\frac{1 \text{ Candela}}{\text{m}^2}$	Nit	Stilb	BOUGIE HECTOMÈTRE CARRÉ	Apostilb	Milli- apostilb	Micro- apostilb	Lambert	Milli- lambert	Micro- lambert	Foot- lambert	Candle Per Sq. ft.	Candle Per Sq. Inch
1 Nit (nt)	$\frac{1 \text{ Candela}}{\text{m}^2}$	1	10^{-4}	10^4	3.14	3.14×10^3	3.14×10^6	3.14×10^{-4}	3.14×10^{-1}	3.14×10^2	2.919×10^{-1}	9.29×10^{-2}	6.452×10^{-4}
1 Stilb (sb)	$\frac{1 \text{ Candela}}{\text{cm}^2}$	10^4	1	10^8	3.14×10^4	3.14×10^7	3.14×10^{10}	3.14	3.14×10^3	3.14×10^6	2.919×10^3	9.29×10^2	6.452
1 Bougie Hectomètre Carré	$\frac{1 \text{ Candela}}{(100\text{m})^2}$	10^{-4}	10^{-8}	1	3.14×10^{-4}	3.14×10^{-1}	3.14×10^2	3.14×10^{-8}	3.14×10^{-5}	3.14×10^{-2}	2.919×10^{-5}	9.29×10^{-6}	6.452×10^{-3}
1 Apostilb (asb)	$\frac{1 \text{ Candela}}{\pi \times \text{m}^2}$	3.183×10^{-1}	3.183×10^{-5}	3.183×10^3	1	10^3	10^6	10^{-4}	10^{-1}	10^2	9.29×10^{-2}	2.957×10^{-2}	2.054×10^{-4}
1 Milli- apostilb (masb)	$\frac{1 \text{ Candela}}{\pi \times 100 \times \text{m}^2}$	3.183×10^{-4}	3.183×10^{-8}	3.183	10^{-3}	1	10^3	10^{-7}	10^{-4}	10^{-1}	9.29×10^{-5}	2.957×10^{-5}	2.054×10^{-7}
1 Micro- apostilb (μ asb)	$\frac{1 \text{ Candela}}{\pi \times 10^6 \times \text{m}^2}$	3.183×10^{-7}	3.183×10^{-11}	3.183×10^{-3}	10^{-6}	10^{-3}	1	10^{-10}	10^{-7}	10^{-4}	9.29×10^{-8}	2.957×10^{-8}	2.054×10^{-10}
1 Lambert (L)	$\frac{1 \text{ Candela}}{\pi \times \text{cm}^2}$	3.183×10^3	3.183×10^{-1}	3.183×10^7	10^4	10^7	10^{10}	1	10^3	10^6	9.29×10^2	2.957×10^2	2.054
1 Milli- lambert (mL)	$\frac{1 \text{ Candela}}{\pi \times 10^3 \times \text{cm}^2}$	3.183	3.183×10^{-4}	3.183×10^4	10	10^4	10^7	10^{-3}	1	10^3	9.29×10^{-1}	2.957×10^{-1}	2.054×10^{-3}
1 Micro- lambert (μ L)	$\frac{1 \text{ Candela}}{\pi \times 10^6 \times \text{cm}^2}$	3.183×10^{-3}	3.183×10^{-7}	3.183×10	10^{-2}	10	10^4	10^{-6}	10^{-3}	1	9.29×10^{-4}	2.957×10^{-4}	2.054×10^{-6}
1 Foot- lambert (ftL)	$\frac{1 \text{ Candela}}{\pi \times \text{ft}^2}$	3.426	3.426×10^{-4}	3.426×10^4	10.764	1.0764×10^4	1.0764×10^7	1.0764×10^{-3}	1.0764	1.0764×10^3	1	0.3183	2.14×10^{-3}
1 Candle Per Sq. ft.	$\frac{1 \text{ Candela}}{\text{ft}^2}$	1.0764×10	1.0764×10^{-3}	1.0764×10^5	3.382×10	3.382×10^4	3.382×10^7	3.382×10^{-3}	3.382	3.382×10^3	3.14	1	6.944×10^{-3}
1 Candle Per Sq. inch	$\frac{1 \text{ Candela}}{\text{inch}^2}$	1.55×10^3	1.55×10^{-1}	1.55×10^{-5}	4.869×10^3	4.869×10^6	4.869×10^9	4.869×10^{-1}	4.869×10^2	4.869×10^5	4.524×10^2	1.44×10^2	1

UNITS OF LUMINANCE



Below each bar logarithmic units and their subdivisions are given.
Above the nit bar natural figures are given.

USAF SCHOOL of AVIATION MEDICINE

derived by H W ROSE, dept of ophthalmology
drawn by L F CAROL, instructional aids sect.

THE APPARENT LENGTH OF A LINE AS A FUNCTION OF ITS INCLINATION¹

by William T. Pollock and A. Chapanis
The Johns Hopkins University

That people overestimate vertical distances as compared with horizontal distances was first pointed out by Wundt (2) in 1858. He required his subjects to adjust a pair of dividers until the separation between the two tips appeared equal to a standard distance--a 25 mm. space between two horizontal points. Adjustments were made with the dividers held in positions which varied from 0° to 90° with the horizontal. Wundt found that progressively smaller distances between the tips of the dividers appeared equal to the standard horizontal distance as the dividers were rotated from 0° to 90°. The maximum overestimation of distance occurred when the judged distance was vertical. The illusory effect under these conditions amounted to 20 per cent of the actual distance involved, that is, a 20 mm. vertical distance appeared equal to the 25 mm. horizontal distance.

A more recent experiment by Shipley, Nann, and Penfield (1) used solid lines instead of open distances between points. These investigators presented subjects with pairs of lines equal in length, but at different angular orientations. The positions varied from 0° (horizontal) to 90° (vertical) in 15-degree steps. The subject's task was to judge which of the two lines looked longer. Their results confirmed generally Wundt's data with one interesting exception: The maximum overestimation of length occurred at approximately 60° from the horizontal, that is, lines tilted at 60° were reported even longer than those at 90°. Obviously, their technique did not permit them to quantify the amount of the illusion.

Although the overestimation of the vertical is a very old illusion, we have not been able to find any other experiments which have studied it as a function of the angular position between the vertical and the horizontal. The experiments reported here are an extension of the same sort of work that Wundt and Shipley, *et al.*, have reported. Our experiments, however, differ from the earlier work in one or more of the following respects: we have tested more angular positions, have used solid lines of two different basic lengths, and have quantified the apparent lengths of the lines.

EXPERIMENT I

Apparatus, Subjects, and Procedure

Experimental situation. -- The apparatus permitted the subject to adjust the length of a variable line until it appeared to match the length of a standard line. A schematic view of the experimental situation is shown in Figure 1. The subject sat 15 feet from a six-foot square, white screen. Two black lines were located near the center of the screen with the centers of the lines fixed in a horizontal plane. The line on the subject's right was of constant length; the other line was variable. The subject was able to adjust the length of the variable line by means of the cable and pulley arrangement shown in Figure 1. The variable line assembly consisted of a housing containing a slide, and was so constructed that the break between the housing and the slide was not apparent from the subject's position.

A screen brightness of 1.25 equivalent foot candles was provided by a lamp located in a reflector clamped to the subject's chair. No other lights were on during experimental runs.

¹This research was done under Contract N5-ori-166, Task Order I, between the Systems Coordination Division, Naval Research Laboratory, Office of Naval Research and the Johns Hopkins University.

Subjects. -- Twenty different subjects were used in each of the two series of trials. The ages of the subjects ranged from 17 to 26 years. Subjects were screened to eliminate those with poor visual acuity or marked astigmatism.

Procedure. -- The basic experiment consisted of two parts. The first made use of a three-inch standard line and the second used a six-inch standard. In both cases the lines were one-half inch wide. For tests with the three-inch standard, the centers of the standard and variable lines were nine inches apart; for the six-inch tests, the separation was 18 inches.

The standard line was always shown in either the horizontal or the vertical position. The variable line was placed in one of the 10° positions from 0° to 170°. Since each position of the standard occurred with each position of the variable, a total of 36 comparison conditions resulted. In addition, each subject was given two trials under each condition, making a total of 72 judgments per subject.

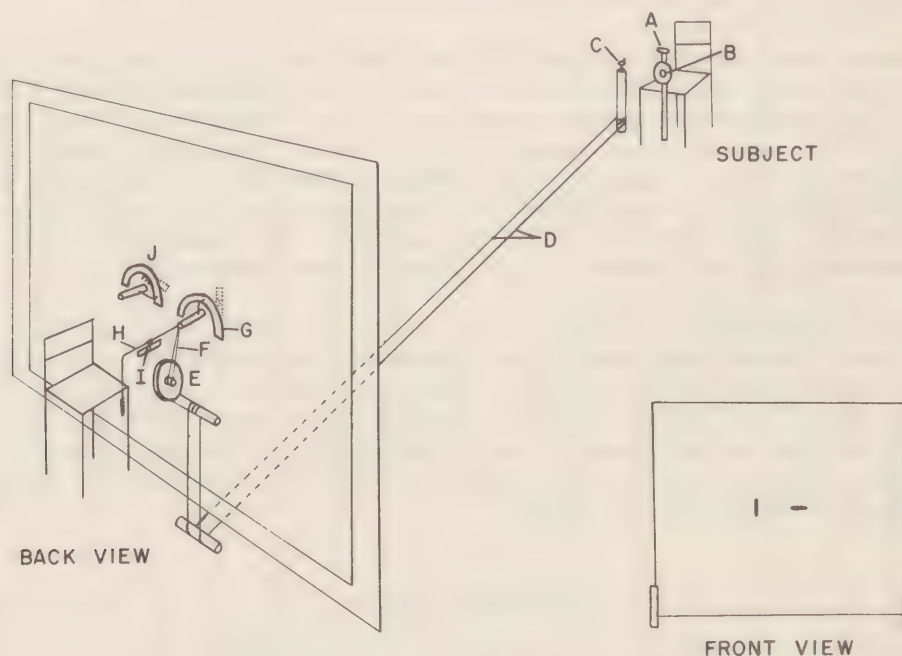


Figure 1. Schematic view of the experimental situation. A is the subject's chin rest; B the photoflood lamp which illuminated the screen; C the subject's control knob; D control cables; E a reduction system; F control cords; G a protractor; H a follower for the slide on the variable line; I a scale; and J the standard line assembly.

The 72 trials were presented in a randomized order. The experimenter set the variable line at its maximum length on the odd-numbered trials and at its minimum length on the even-numbered trials. The subject was given unlimited time to equate the lengths of the two lines. Binocular viewing with uncontrolled fixation, but with no head movement, was permitted.

Results and Discussion

Constant errors. -- The curves in Figure 2 show the mean constant errors for the judgments with both the three-inch and six-inch standard lines. Subjects were quite accurate in equating the lengths of the two lines when they had the same orientation. Thus, when the two lines were at 0° (horizontal), the constant errors of the settings were nearly zero. But as the angle between the two lines increased, the constant error increased negatively.

STANDARD HORIZONTAL

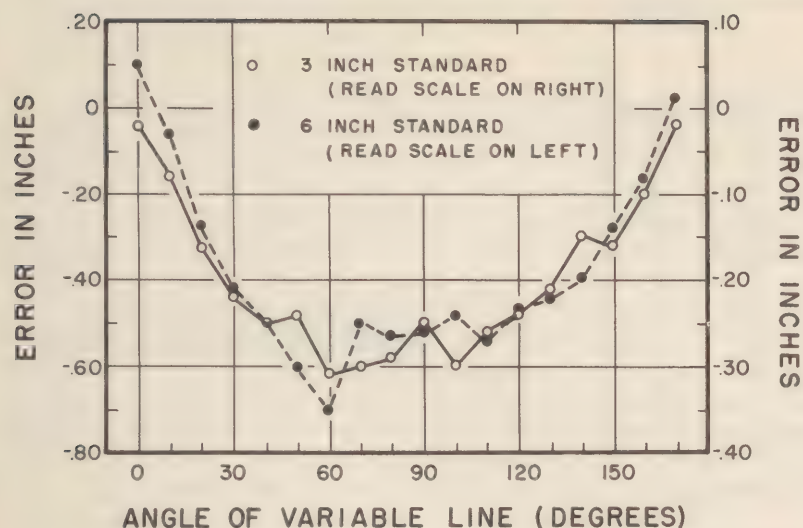


Figure 2. Mean constant error curves for judgments made with the three- and six-inch standard horizontal lines. The negative error of 0.52 inches at 90° (solid point), for example, means that a vertical line of 5.48 inches looked as long as the standard horizontal line which was 6 inches long. Each point is an average of 40 judgments.

length. Thus, the greater the angular difference between the vertical standard and the variable line, the longer the variable line must be in order to equal the standard. This is another way of saying that the apparent length of a line increases as the angle between the line and a horizontal line increases.

However, we must qualify this general rule by pointing out that the maximum overestimation of length is produced by a line tilted at 80° for the three-inch standard, and at 70° for the six-inch standard.

Variability. -- As might be expected, the variability of the judgments was also dependent on the angular position of the standard line. Generally, the greater the angular difference in the positions of the standard and variable lines, the greater the variability of the judgments. The curves in Figures 4 and 5 show that the same general rule holds for the data obtained with the horizontal and vertical standards.

Individual differences. -- There were marked individual differences between subjects in the judgments they made, as is illustrated in Figure 6. The curve at the top of the figure is for a subject who made

This means that the apparent length of the variable line increased as the angular difference between it and the horizontal position increased. Note, however, that the greatest apparent length of the variable line occurred when the line was tilted at an angle of 60° .

The curves in Figure 3 show the results with the vertical standard. Paralleling the data for the horizontal standard, when both lines are vertical the judgments of length contain very little error. In other respects also the data of Figure 3 demonstrate the same dependence of apparent length on angular position as demonstrated in Figure 2, but in a slightly different way. Figure 3 shows how long the lines must be in various angular positions in order to appear equal to a given vertical

STANDARD VERTICAL

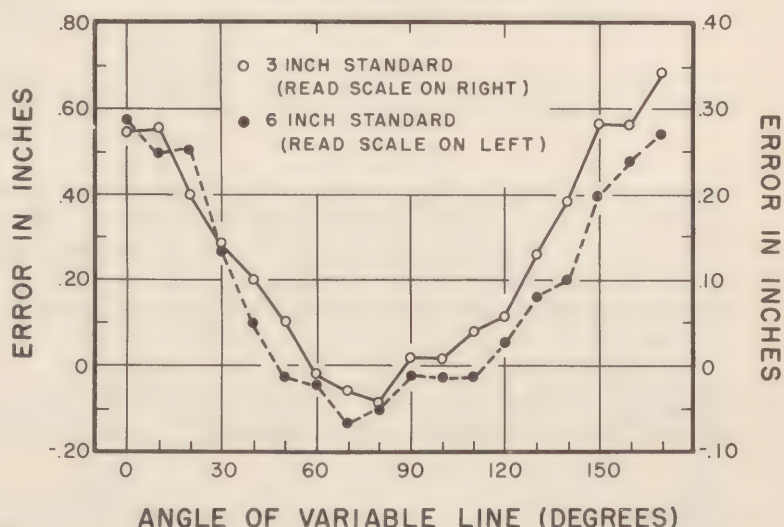


Figure 3. Mean constant error curves for judgments made with the three- and six-inch standard vertical lines. A positive error of 0.10 inches at 40° (open circle), for example, means that a line 3.10 inches long tilted 50° to the left of vertical looked as long as the standard vertical line which was 3 inches long. Each point is an average of 40 judgments.

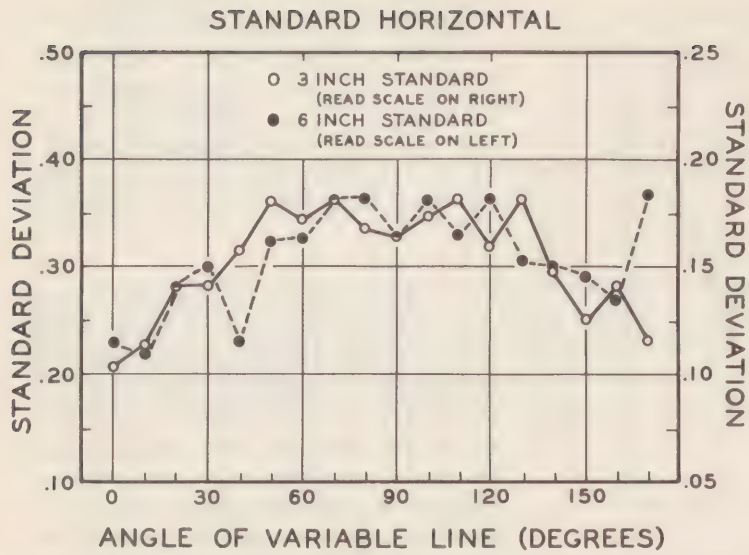


Figure 4. Variable error curves for the three-inch and six-inch horizontal standard data.

Figure 5. Variable error curves for the three-inch and six-inch vertical standard data.

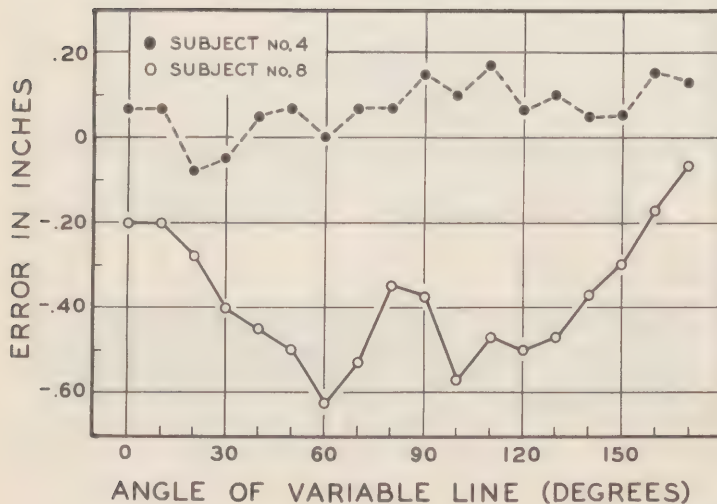
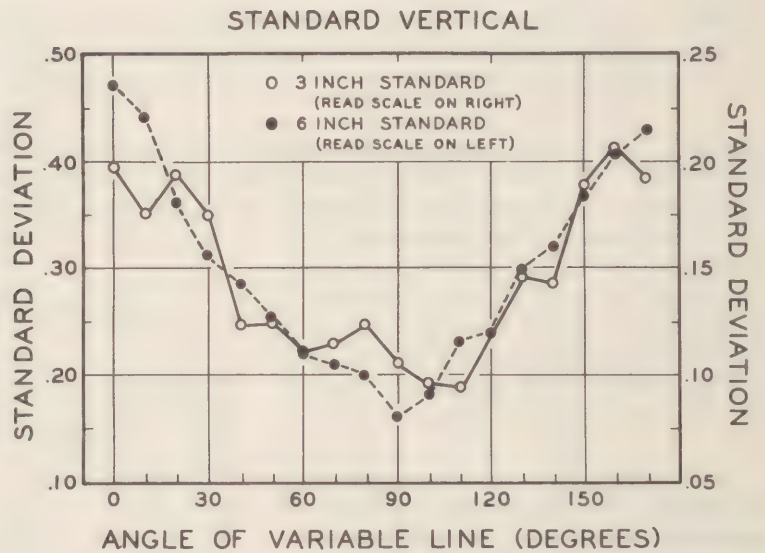


Figure 6. Constant error curves chosen to illustrate the wide individual differences found in this experiment. Both these subjects worked with a three-inch horizontal standard. Each point is an average of two judgments.

approximately the same setting -- and apparently experienced no illusory effects -- for all angular positions of the variable line. At the bottom is the curve for a subject who responded by systematically overestimating the length of the variable line as its angle with the horizontal line was increased.

Differences between the constant errors at the various angular positions. -- The significance of the differences between the mean constant errors for the various angular positions of the variable line was tested by conventional statistical techniques. In general, a difference of 0.04 inches for the three-inch data, or of 0.10 inches for the six-inch data, is significant at the 5 per cent level of confidence. A difference of 0.06 inches for the three-inch data, or 0.14 inches for the six-inch data, is significant at the 1 per cent level.

Of especial interest is the finding that for the three-inch and six-inch horizontal standards, the difference between the 90° and the 60° data is significant at $p = <.01$; and that with the three-inch and six-inch vertical standards, the 90° and 70° data differ at $p = .05$. All these comparisons involve angular positions of the variable line which produced larger negative constant error scores than the comparable vertical line. This means that at these angular positions the lines looked longer than vertical lines. Since all these comparisons were significant, the conclusion is that lines inclined 10-30 degrees to the left of vertical look longer than any other lines of equal length.

A perplexing feature of these data is that lines inclined 10-30 degrees to the right of vertical produce less overestimation than lines tilted symmetrically to the left of vertical. A possible explanation of this discrepancy might be in terms of the relative positions of the variable and standard lines. In this experiment the variable line was always to the left of the standard. Such a fixed relative position might possibly be the cause of the asymmetry in our data. Experiment II was performed to test this hypothesis.

EXPERIMENT II

Apparatus and Procedure

Apparatus. -- The apparatus used in this experiment was similar to that of Experiment I. The main differences were in the shape of the presentation screen and in the control of the length of the variable line by the subject.

The screen in this experiment was a white circle, five and one-half feet in diameter, mounted on a stand so as to permit rotation of the screen about its center. The variable and standard line assemblies were those used in the six-inch standard trials in Experiment I. They were located near the center of the screen with their centers 18 inches apart. By rotating the screen assembly about its center, the two test lines could be placed in any position relative to each other.

In this experiment, the subject did not have direct control over the length of the variable line. Instead, he signalled the experimenter, who was behind the screen, whether to lengthen or shorten the variable line.

Procedure. -- This experiment tested the variable line only at angles of 0° , 30° , 60° , 70° , 80° , 90° , 100° , 110° , 120° , and 150° . In addition, the variable line was tested above, below, to the right of, and to the left of, the standard line. The standard line was always horizontal.

The final variable tested was the direction of movement of the slide in the variable line. In Experiment I, the slide of the variable line assembly always moved upward as it got longer. In this experiment both directions of slide movement were tested.

These three variables, consisting of ten angular positions of variable line, four relative positions of the variable and standard lines, and two directions of movement of the slide, produce 80 experimental conditions. The conditions were assigned to four groups of ten subjects each; the subjects of any particular group worked with the 20 combinations of angular positions and directions of slide movement, but at a single relative position of the variable and the standard lines. In short, the variance between groups of subjects is confounded with the variance due to the relative positions of the lines.

Results and Discussion

The curve of mean constant errors of all judgments without regard to the relative position of the two lines is presented in Figure 7. This error curve is similar in shape and

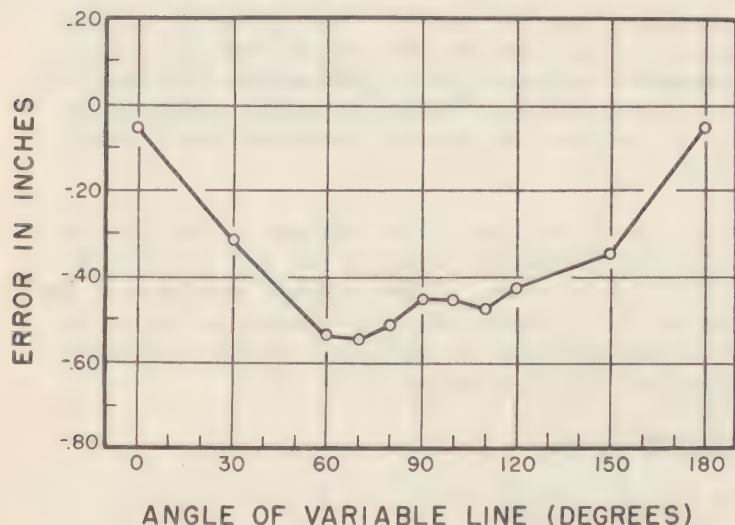


Figure 7. Mean constant error curve of all the judgments made in Experiment II. The six-inch standard was horizontal. Each point is an average of 80 judgments.

pronounced minima in the 60° - 70° region. This also lends support to the conclusion that the asymmetry of the error curves of Experiment I was not a result of the fixed relative position of the variable and standard lines.

The principal effect of changing the relative position of the lines is to shift the error function up or down. Thus, when the two lines are one above the other, overestimations are not as large as those found when the two lines are side by side (Fig. 9).

The variability of the judgments in this experiment was similar to that of Experiment I. Generally, the greater the angular difference between the two lines, the greater the variability

direction to the constant error curves with a horizontal standard obtained in Experiment I. Note especially that there is still a pronounced asymmetry in the data. Lines tilted at 60° and 70° look longer than those tilted at 110° or 120° . Since this curve combines data for all four relative positions of the standard and variable lines, we conclude that the asymmetry cannot be ascribed to the position of the two lines.

The mean constant errors of the judgments as a function of the relative positions of the two lines are given in Figure 8. Although they are less smooth, the curves approximate roughly the curves found in Experiment I. With one exception (standard to the left, which, incidentally, is the situation tested in Experiment I) the curves show

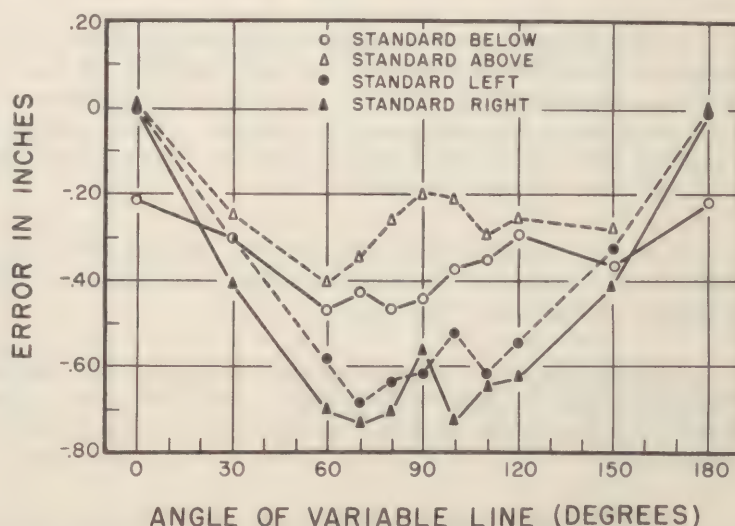


Figure 8. Mean constant error curves of the judgments with relative position of the variable and standard lines as the parameter. The legend refers to the position of the variable relative to the standard line. The six-inch standard line was horizontal. Each point is an average of 20 judgments.

of the judgments. As expected from the previous experiment, the subjects contributed a significant source of variance to these data. Other significant sources were the relative positions of the lines, the angular positions of the variable, and the interaction of these two factors. The direction of movement of the variable line slide contributed an insignificant fraction to the total variance. The significant interaction of angular position and relative position indicates that the shapes of the error functions for the relative positions of the lines are different, but it does not negate the conclusion concerning the asymmetry of the curves with minima in the 60° - 70° region.

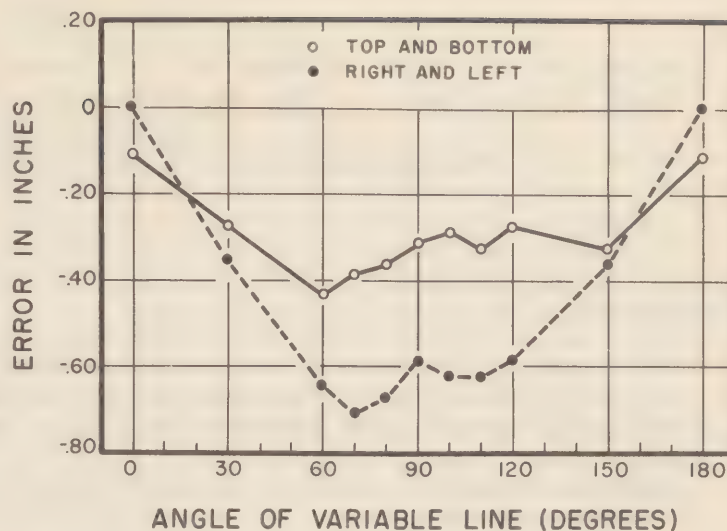


Figure 9. The top and bottom data, and the left and right data, of Figure 8 have been combined here. Errors of judgment are greater when the two lines are side-by-side; less when they are one above the other.

SUMMARY AND CONCLUSIONS

In the first of two experiments reported here, subjects adjusted the length of a variable line until it appeared to be as long as a standard line. There were two sizes of standard line, 3 and 6 inches, and each was presented vertically for half of the trials and horizontally for the other half. The variable line was presented in each of the 10-degree positions from 0° (horizontal), through 90° (vertical), to 170° .

The principal findings of the first experiment are:

(1) Vertical lines look longer than horizontal lines of the same length, but lines tilted 10° - 30° to the left of vertical appear longer than lines tilted to any other position. The results are asymmetrical, because lines tilted to the right of vertical do not look as long as those tilted to the left of vertical.

(2) The variability of the settings increases the greater the angle between the variable and horizontal lines.

(3) There are enormous differences between subjects in the patterns of settings made at the various angles. A few subjects apparently experienced no illusory effects since they adjusted the variable line to the same physical length irrespective of its orientation. Other subjects showed exaggerated overestimations of the variable line for vertical and near vertical positions.

In the first experiment, the variable line was always to the left of the standard, and it was natural to assume that this position effect had somehow produced the asymmetry noted in paragraph 1 above. This hypothesis was tested in the second experiment which alternatively showed the variable line above, below, to the right, and to the left of the standard. The results of this experiment generally confirm the data of the first experiment in showing that lines tilted 10° - 30° to the left of vertical look longer than lines tilted to any other position. In addition, the second experiment shows that this asymmetry in the results is not a function of the relative positions of the variable and standard lines. In general, however, overestimations of length are smaller when the two lines are one above the other; overestimations are greater when the two lines are side-by-side.

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Discussion:

- A question was raised from the floor as to whether Dr. Chapanis had investigated the handedness of the subjects. It was suggested that there might be a relation between handedness and judgment of the apparent length of a line.
- Dr. Chapanis replied that he failed to see the possibility of such a relation since the judgments were binocular.
- Dr. Blackwell asked Dr. Chapanis if he had considered the possibility of explaining the results in terms of peculiarities of neurological mapping.
- Dr. Chapanis replied that he had considered such an explanation but had found it unable to account for the full range of effects discovered.
- Dr. Fry asked if the effects occurred for people who are accustomed to using only one eye in binocular vision, that is, people who suppress their vision in one eye. Dr. Fry reported that if a person habitually uses only one eye, objects seem considered less wide than if the person habitually uses both eyes.
- Dr. Chapanis replied that their experimental subjects had not been required to use rigid fixation but had looked back and forth between the two objects to be compared. This fact seems to rule out a lot of explanations which various people favor.
- Dr. Sloan commented that this must mean that the effect is somehow related to the pattern of eye movements.
- Dr. Mote commented that illusions of this sort can be obtained with short exposures, for example the traditional Muller-Lyer illusion is preserved at short exposures.
- Dr. Crozier commented that one can get the Muller-Lyer illusion with a portion of the test object in one eye and the rest in the other eye.
- Group Capt. McCulloch commented that lumber-jacks are aware of the illusion which Dr. Chapanis has reported. In cutting timber, the lumber-jack always allows for the fact that the standing tree appears shorter than it actually is.

ON THE DARK-ADAPTATION CONTOUR

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1. In current thinking about the time-course and the intensity levels of dark-adaptation there still prevails altogether too static a conception of the analytical and diagnostic significance of the structure of the dark-adaptation contour. It is almost canonical to envisage this contour, with a given method for estimation of progressively lower "threshold" intensities, as exhibiting two distinct branches: the first, photopic branch descends typically on a curve of decreasing (negative) slope, followed by a plateau terminating at 5 to 10 minutes dark-adaptation with an abrupt, smooth, gradual descent to a much lower quasi-constant "fully dark-adapted" level reached after 30 to 45 minutes in darkness. This picture, for extra-foveal test-patches of ca. 3° subtense (or for larger fields centrally fixated), has often been presented. The particular conception of photopic (cone) and scotopic (rod) adaptation processes and levels to which it has led has been rather firmly held as depicting the operation of 2 essentially independent processes during the course of dark-adaptation.

The extent of the putative independence of the operations referred to as those of the 'cone' and the 'rod' dark-recovery processes has not been studied adequately. It cannot be held that the use of approximately monochromatic lights, with the involvement of color experience on the scotopic segment, serves as an independent index of rod-cone separation. This is because conditions arise in which color ceases to appear well before arrival at the cone-rod "knee"; whereas cases also occur in which color is experienced fairly well down on the rod section.

2. Commonly, the course of dark-adaptation has been estimated by the use of some form of "limits" procedure involving brief exposures of a small test-patch of simple form (circle; square).

It is desirable to examine also the properties of dark-adaptation as revealed by threshold determinations when the test-image is not a simple circle or square. It is probable that a role of perimeter of image is revealed in such tests, even below the threshold for pattern resolution. If there can be demonstrated an effect of this sort, involving a changed relation between photopic and scotopic contours, then it would probably be necessary to exercise additional caution in the diagnostic use of "mesopic" dark-adaptation thresholds such as are now attracting attention.

In relation to the problem of the visual significance of the pecten of bird's eyes, and to the question of resolution of a pattern with interrupted light, flicker experiments were made with simple and subdivided square fields (J. Gen. Physiol., 27, 401, 1943-44). A small 3° square image was divided into 4 small squares (same total area). It gave rise at 8° temporally to $F - \log I$ contours, at various light-time fractions, markedly different from those obtained with the simple 3° square. They were closely similar to those obtained with a simple 6° square. Note that with the subdivided 3° square and the 6° the total perimeter of light/dark separation was double that for the 3° square.

The qualitative difference associated with the subdivision of the 3° square was that the 'cone' segment of the duplex contour was pushed to higher intensities, enlarged, and made steeper; while the 'rod' segment, also pushed to higher intensities, became smaller.

3. The experiments here cited were made with a briefly presented target (0.04 sec.), 2° square at the retina, centered 10° on the temporal side of the fovea of one eye (4 observers). The image was in the form of 5 vertical bars of light separated by equally broad opaque bars.

If resolution of bars is taken as 'threshold' in a dark-adaptation test, the ordinary 'canonical' form of duplex contour is obtained.

When detection of light is the 'threshold' used, well below the intensity required for visibility of the bars, the effect on the contour is profound. Without careful analysis it is difficult to detect that there is any shape-duplexity present. With white, violet, or blue light there is almost no obvious evidence of a "knee". The final adapted level corresponds to that of the photopic segment (with the same initial light-adaptation) when using a simple 1.°6 square test-field (the same lighted area as for the grid target). The "knee" is a little more obvious with green and orange light. The "fusion" of the usual 2 segments is even more extreme than in data such as provided by Nagel and Piper, which led at first (Hecht) to a mistaken conception of the dark-adaptation curve.

4. Detailed examination shows that, just as in the case of the change of the flicker curves by subdivision of the test-field, the 'cone' segment is pushed to higher intensities, and enlarged; while the 'rod' segment, also moved to higher intensities, is made smaller.

VISUAL ACUITY AND ANGULAR SPEED OF OBJECT

by

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Introduction

It is an every day experience, that an object moving fast through the visual field is seen only as a blurred image. This blurring can limit the size of objects or detail of objects seen by a pilot in a fast moving airplane near the ground. The use of jet planes for ground support in hilly country makes fast recognition of targets and signal devices indicating the frontline a necessity. It is therefore of interest to the pilot to know how far blurring limits his ability to recognize objects of specified size.

The size of objects at the limit of recognition can be described by the reciprocal value of their angular subtense in minutes. That is as a dimension equal to a visual acuity. The influence of speed of an object moving relative to the eye in a straight line is obviously dependent on the distance from the eye to the object and the angle between the line of vision and the direction of relative movement of the object. This movement is then most easily described as an angular movement, or the change per unit time of the angle between the lines of vision at different times.

Experimental Methods

The test apparatus built for this purpose consists of a projector on a turntable (Fig. 1) which can rotate with angular speeds ranging from $3.6^\circ/\text{sec}$ to $360^\circ/\text{sec}$. Four different gears and a variable drive provides this range. The continuously variable drive consists of a driving cone, an idler wheel, and a driven cone. A synchronous motor drives the driving cone. The idler wheel is shifted back and forth by a second motor, which is switched off at the ends of the range automatically. By the rotating projector the image of a visual acuity test is thrown on a bent projection screen, which is 120 cm high, 360 cm. long and part of a cylinder surface of 300 cm. radius. The rotation axis of the turntable, as well as the test person, are close to the axis of the cylindrical screen (Fig. 2). This screen is painted with flat white enamel. The test characters are similar to the Morse code. They consist of 9 squares each. One square forms each one of two "dots", two squares are used to form each one of two "dashes" and the rest of three squares are intervals between dashes and dots. With two dots and two dashes six combinations are possible. The patterns were provided in white on black and black on white. The slides were mounted between glass in 5 cm. by 5 cm. slides. The patterns were made



Figure 1. Rotating Projector.

photographically with microfilm film, developed 8 minutes in developer DK-50 at 19 degrees centigrade, and printed on Kodalith developed in Kodalith developer. The brightness of the white in the pattern on the projection screen is 42 nit*.

The brightness of the black in the pattern on the projection screen is 0.6 nit. The size of the break or interval in the projected test charts corresponds to the visual acuities in decimal notation: 1.44, 1.0, 0.72, 0.49, 0.34, 0.24, 0.17, 0.12, 0.084, 0.059, 0.042, 0.03. The relation between each two of them is $\sqrt{2}:1$. The voltage for the projection bulb as well as the motors was stabilized at 117 volts. The twelve different sizes of patterns were shown to 36 test persons in a randomized order each time. The twelve patterns of equal size were shown in randomized sequence. Each test pattern was presented in the beginning with an angular speed exceeding the expected recognition speed considerably. The turntable was then slowed down till the pattern was recognized. The test persons were selected for minimum visual acuity of 1.0 on at least one eye with Snellen test characters on a background of 31.8 nit luminance and 1/20 contrast.



Figure 2. Projector Arrangement.

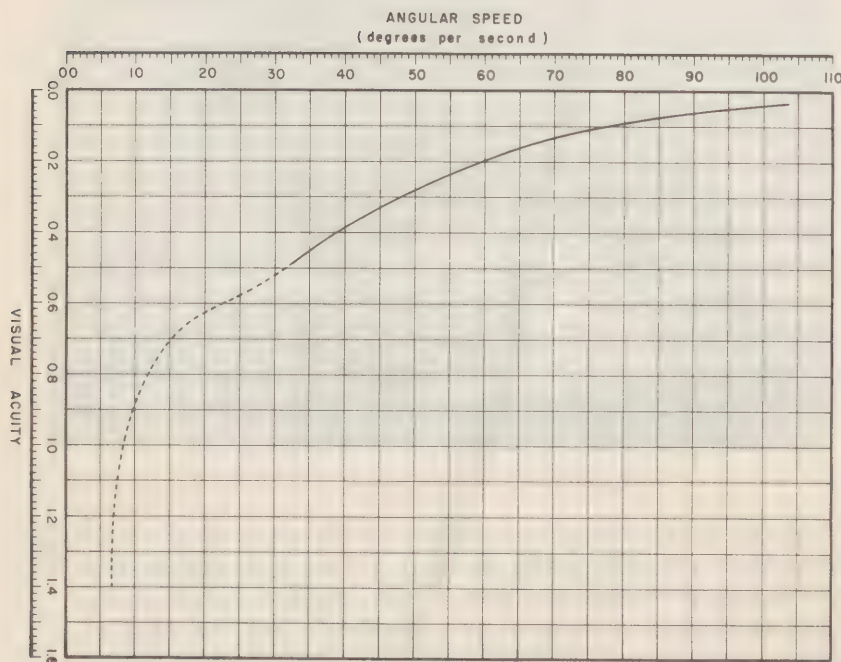


Figure 3. Visual Acuity and Angular Speed of Object 12 determinations for each of 36 test persons, with each visual acuity between 0.03 and 0.49. Less determinations between 0.72 and 1.44.

Results

For 1.0 and 1.4 visual acuity only a small number of measurements could be obtained; even with the slowest speed, 3.6 degrees/sec many test persons did not recognize the pattern without motion. Below 0.49 visual acuity the set of measurements is complete. The average speeds obtained for each visual acuity are given in table I and figure 3. In figure 4, the average results of 3 men with the acuity 1.5 at the Snellen Visual Acuity Test are shown. The curve fitted to the measurements of this latter group is

$$y = 160.72x^2 - 231.62x + 102.87$$

where y stands for angular velocity and x for visual acuity.

*1 nit = 1 candle/m² = 3.14 apostilb = 3.14×10^{-4} lambert = 2.919×10^{-1} ft lambert.

Discussion

The results are represented by a curve with a monotonous decrease. In the part of the curve corresponding to low speeds and high visual acuity even for a group selected for minimum visual acuity 1.0 the curve is mainly determined by native visual acuity. Nearly each test person seems to have been able to follow the projected image at an angular speed of 3.6 degrees/second and therefore the motion of the image was compensated by motion of the eye and only a small blurring effect was observed. At the end of the curve corresponding to high angular speeds and visual acuities below 0.5 it can be assumed that the slope of the curve of this selected group is mainly determined by the blurring effect. It is practically impossible to follow a motion of 100°/second with the eye. The test object was chosen to show clearly the influence of blurring by having a pattern symmetrically arranged around an axis corresponding to the direction of movement. This test object is apparently more difficult to read than the Snellen letters used for selection of personnel. That explains the low number of visual acuity of 1.0 during the experiment in a group of men selected with Snellen letters for a minimum visual acuity of 1.0.

The decrease of visual acuity observed during the experiment is great enough to be of practical value for jet aircraft flying near the ground.

TABLE I

Maximum angular speed of object as function of visual acuity. Twelve determinations for each of 36 test persons, with each visual acuity between 0.03 and 0.049. Less determinations between 0.72 and 1.44.

Visual Acuity	Angular Speed
0.030	103.61
0.042	96.27
0.059	90.84
0.084	82.34
0.12	73.34
0.17	63.12
0.24	54.93
0.34	44.25
0.49	32.29
0.72	14.52
1.00	8.60
1.44	6.82

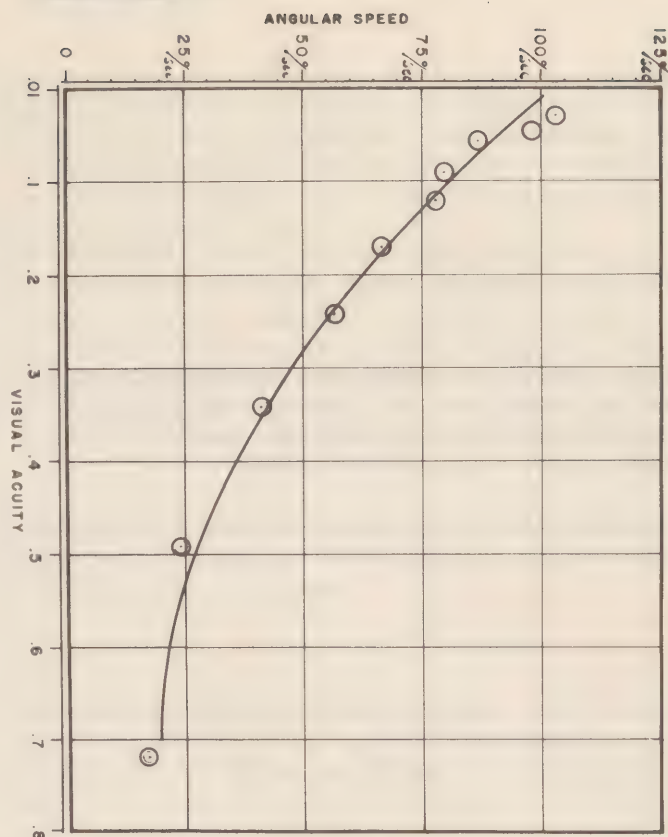


Figure 4. Visual Acuity and Angular Speed of Object. 12 determinations for each of 3 test persons who were selected for minimum visual acuity 1.5 with the Snellen test.

Discussion:

Dr. Mote commented that the angular speed of movement on the retina was not the same as the objective speed due to the fact that the eyes of the subject attempted to follow the movement of the target.

Dr. Rose agreed that this was the case. He stated that at low speeds, the subject could follow the movement of the target very well but at higher speeds, he could not follow it well at all.

Group Capt. McCulloch stated that the situation of practical service interest would be one in which the movement was vertical rather than horizontal. For example, in strafing runs, the movement of ground objects would be vertical. Capt. McCulloch asked Dr. Rose if he had studied vertical movement.

Dr. Rose replied that he had not but that he hoped to do so in the future.

FLASHES OF CLEAR VISION AND NEGATIVE ACCOMMODATION WITH REFERENCE TO THE BATES METHOD OF VISUAL TRAINING

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On rare occasions in clinical practice, a myopic patient is seen who relates that every once in awhile his usually blurred vision suddenly and briefly becomes beautifully sharp without glasses. This evanescent clarity, termed "flashes" of clear vision, cannot be elicited at will in the refracting room and demonstrated with a visual acuity test chart. The skeptical refractionist who wants to believe the patient, has no opportunity to measure this reported will-o'-the-wisp phenomenon.

What are these flashes? Do they occur as a result of a change of the refractive power of the eye (negative accommodation)? How much do they improve vision? These are some of the questions this investigation will attempt to answer.

Bates and his Disciples

Dr. William Horatio Bates, a well-known New York ophthalmologist, was a maverick in his profession. In 1920 he published a book entitled "The Cure of Imperfect Sight by Treatment Without Glasses"¹ and started a school of vision practitioners (or educators) which is vigorous today.

Most of his claims and all of his theories have been considered false by practically all visual scientists. The quotations taken from throughout his book give, in substance, some of his principal ideas.

[In retinoscopy] the observer is so near the subject that the latter is made nervous, and this changes the refraction. This means that it must not be brought nearer to the eye than six feet; otherwise the subject will be made nervous, the refraction for reasons which will be explained later, will be changed, and no reliable observations will be possible.

Bates did not believe that the crystalline lens is the agent of accommodation because of two pieces of evidence. First, after four years of effort, he failed to find alterations in curvature of the anterior surface of the lens during accommodation as indicated by changes in the size of the image of a reflected light source.*

His other evidence against lenticular accommodation was the occasional cases of apparent accommodation in aphakics.** It seemed evident to him that accommodation was effected by changes in the length of the eyeball.***

*Many investigators including Helmholtz had observed the the phenomenon and in more recent years Kirchhof² made dynamic recordings of this third Purkinje image. Allen³ has developed the technique still further.

**The rarity of these cases should be sufficient to make them suspect as a normal method of accommodation. Excellent evidence has been presented that there is no change in the refractive power of the eye in these cases.^{4,5}

***It is interesting to note that it would take about one millimeter change in axial length of the eyeball for each three diopters change of refractive power. Hence a youth accommodating 15 D. would shorten his globe by five millimeters. To the writer's knowledge, no corresponding anterior-posterior corneal movement has ever been reported.

Let us return to quotations from Bates.¹

The obliques are the muscles of accommodation; the recti are concerned in the production of hypermetropia and astigmatism.

Straining to see at the near point produces hypermetropia.

Myopia produced by unconscious strain to see at the distance is increased by conscious strain.

A person may have good vision when he is telling the truth; but if he states what is not true, an error of refraction will be produced, because it is impossible to state or imagine what is not true without an effort.

I may claim to have discovered that telling lies is bad for the eyes.... [causing a change of refraction seen by retinoscopy].

With such a [practically perfect or normal] memory of black, the retinoscope shows that all errors of refraction are corrected.

Persons with normal sight have been able to look at the sun for an indefinite length of time, even an hour or longer, without any discomfort or loss of vision. Even total blindness lasting a few hours has been produced. Organic changes may also be produced. Inflammation, redness of the conjunctiva, cloudiness of the lens and of the aqueous and vitreous humors, congestion and cloudiness of the retina, optic nerve and choroid, have all resulted from sun-gazing. These effects, however, are always temporary. Some persons who have believed their eyes to have been permanently injured by the sun have been promptly cured by central fixation, indicating that their blindness had been simply functional.

In his book, Bates reported some experiments on animals, which have been criticized for their lack of proper techniques and a flouting of basic facts of anatomy and pharmacology.

Later editions of his book were published by his wife after his death in 1931. They were watered-down and more cautious.^{6,7} In the latter it was no longer claimed that imagining black could be used as a substitute for anesthesia in surgery, nor was it specifically stated that one should look directly at the sun. The original theories and most claims remained.

The fundamental principles of treatment are based on relaxation which, it is implied, is supposed to reduce to the vanishing point, all types of ametropia and ideally beget permanent emmetropia for its fortunate follower. Relaxation is gained as follows:⁷

1. Resting the eyes.
2. Palming (excluding light and seeing maximum black).
3. Swinging (a gentle rotary motion of the trunk with the toes fixed).
4. Memory.
5. Imagination.
6. Flashing* or blinking (furtive glances and blinking from an eyes-closed position).

*It is to be noted that Bates did not use the term "flash" as it is used in this paper, to denote a sudden transient increase of visual acuity.

7. Central fixation (opposite of staring -- looking all about an object).
8. Sun treatment (eyes closed, later open them but look downward).

Many other books have been published on the Bates method but few of them have offered anything original.⁸⁻¹² Most authors since Bates have leaned on him completely for scientific backing. In England, Price¹³ followed the basic practices of Bates but did not adopt all of his theory. Price's book is moderate. While he does believe that strain is the basis of poor vision, he does not take sides in the accommodative theory by which poor vision is supposed to improve. Furthermore, he made none of the extraordinary claims found in Bates' original book. One cannot help but feel that an honest attempt was made by Price to get to the basis of the reported phenomenon of flashing.

Mrs. Margaret Darst Corbett of Los Angeles, California, is a widely known, active and enthusiastic Bates practitioner who has developed a new group of teachers of the Bates method. Her two books^{14, 15} show that she has experimented and adopted new techniques. The theory of Bates is at the core of her practices and she eulogizes it. A few quotations will illustrate her viewpoint.

"...vision is nine-tenths mental and only one-tenth physical.

"Near-sighted eyes need much done for them to bring them to normalcy. First they must have their tension relaxed so that the oblique muscles that belt the eye too tightly about the middle will let go. Then, the recti muscles must be strengthened so that they can flatten the eyeball for the distant focus; and in addition their endurance must be built up so that they can maintain their hold on the eyeball longer than a mere second or "flash" which most near-sighted eyes can get after just a little relaxation.

"Myopic eyes of clients get a flash - a touch of normal vision. Suddenly the oblique muscles let go and the recti contract, shaping the eyeball normally for a moment or two so that the entire panorama stands out perfectly just as with normal vision."

It would seem that in Mrs. Corbett's view, the "nine-tenths mental" part of vision acts to bring about changes in its "one-tenth physical" part.

"....carefully avoid squinting, or squeezing the lids, to clear vision. This is trick vision and injures the eyes. We want only normalcy, no tricks.

"Hold in the fingers of both hands a soft rubber ball. Squeeze it flat from front to back. Let it swell out round again. Then squeeze it around the middle so that it bulges long from front to back. Let it come round again. Watch the ball change shape from a lozenge to an eggshape. Do this repeatedly, rhythmically, saying aloud

Squeeze it flat from front to back
let it come round again
Squeeze it long from front to back
let it come round again."

This doggerel of Mrs. Corbett presumably suggests the changing shape of the eyeball and through autosuggestion, a better control of ametropia is supposed to be gained.*

* Not one to be limited to visual horizons, Mrs. Corbett now applies the Bates technique to deaf ears.

The intellectual giant of the Bates group is the well-known expatriate British author, Aldous Huxley. Whereas, the books of Mrs. Corbett are best for learning the practice in cookbook fashion, the book of Huxley¹⁶ is, without question, the best written and the most profound. It is relatively cautious in regard to the theories and to some of the claims of Bates.

Huxley had two reasons for writing this book. First as a debt of gratitude to Dr. Bates and to Mrs. Corbett who helped him to improve his own vision which was poor as a result of a bilateral keratitis acquired at the age of 16. His second reason was to "correct the methods of visual education with the findings of modern psychology and critical philosophy". Huxley speaks thus:

"Vision is not won by making an effort to get it; it comes to those who have learned to put their minds and eyes into a state of alert passivity, of dynamic relaxation.

"This guess [The Bates theory of the mechanism of accommodation] may be correct; or it may be incorrect. I do not greatly care. For my concern is not with the anatomical mechanism of accommodation, but with the art of seeing - and the art of seeing does not stand or fall with any particular physiological hypothesis. Believing that Bates's theory of accommodation was untrue, the orthodox have concluded that his technique of visual education must be unsound. Once again this is an unwarranted conclusion, due to a failure to understand the nature of an art, or psycho-physical skill."

Huxley, then, while showing respect for Bates, is not tied to his theories as most of the others appear to be. He seems willing to stand on improved visual acuity as the important demonstrable phenomenon in the Bates method.

Orthodox Reaction to Bates and Disciples

Most visual scientists who read Bates or his disciples have been immediately repelled. The theories appear so wild, the evidence so poor, or lacking, in contrast to abundant and strong evidence by investigators of known scrupulous honesty and carefulness that the Bates techniques are thought to be unscientific.

This understandable reaction is seen in an answer to the Bates method by Sorsby,¹⁷ a well-known British ophthalmologist. One by one he pointed out the flaws in the theories of Bates and criticized his experimental techniques with complete justification. Huxley's rebuttal was sharp and to the point.

"... Sorsby entirely fails to distinguish between two totally different things: the primary evidence confirming the existence of certain phenomena, and the secondary evidence adduced to substantiate the hypothesis, in terms of which these phenomena are explained. The phenomena, which Bates sought to explain in terms of his unorthodox theory of accommodation, were those marked improvements in vision, which regularly followed the practice of certain educational techniques. The evidence for the occurrence of such phenomena can be supplied by thousands of persons who, like myself, have derived benefit from following the procedures in question, and by the scores of conscientious and experienced instructors who teach the method. If Mr. Sorsby really wanted to know about this evidence, he would get in touch with a few reliable teachers, ask permission to watch them at work and, if his own vision is defective, take a course of visual re-education. Instead of that he seeks to discredit the whole idea of visual re-education by denying the validity of the experiments used by Bates to support his explanatory hypothesis.

"... Even if this secondary evidence were untrustworthy, even if the

hypothesis supported by that evidence could be proved to be incorrect, this would make absolutely no difference to the facts which that hypothesis was originally intended to explain."

Duke-Elder¹⁸, in reviewing Huxley's book, was strong in condemnation of its theories but allowed the practice to a limited degree.

"Whatever be the value of the exercises, it is quite unintelligent of Huxley to have confused their advocacy with so many misstatements regarding known scientific facts. It has been shown that the hypothesis upon which these methods of treatment are based is wrong; but Huxley, while admitting he is ignorant of the matter and unqualified to speak, contends that this is of no importance because the method works in practice and gives good results; it come into the category of "art" not of "science". The argument is perfectly allowable, for in other spheres than medicine empirical methods have often produced effective results the rationale of which may be mysterious. The most stupid feature about his book, however, is that he insists throughout on the physiological mechanism whereby these exercises are supposed to work. It would at least have been logical if he had continued to allow the reader to assume that he was speaking in ignorance of anything except results.

"There would appear to be no doubt that these exercises have done Aldous Huxley himself a great deal of good. Every ophthalmologist knows that they have made quite a number of people with a similar functional affliction happy. And every ophthalmologist equally knows that his consulting-room has long been haunted by people whom they have not helped at all."

Duke-Elder concluded by saying,

"For the simple neurotic who has abundance of time to play with, Huxley's antics of palming, shifting, flashing, and the rest are probably as good treatment as any other system of Yogi or Coué-ism. To these the book may be of value. It is hardly possible that it will impress anyone endowed with common sense and a critical faculty. It may be dangerous in the hands of the impressionable who happen to suffer from glaucoma or detachment of the retina...."

Lancaster, the late dean of American ophthalmologists, did not believe that any change takes place in the size or shape of the eyeball with exercise. In discussing eye exercises for the improvement of visual function, he said¹⁹:

"If one studies the various publications with an open mind, searching for the things which will explain why the public wants this treatment, one will be forced to admit that burried in a mass of what to ophthalmologists seem foolish gestures and performances, best defined as hocus-pocus, there are sound and fruitful ideas. It is these that account for the survival and spread of the cult. It is certainly not foolish to believe that people can be taught to use their vocal organs in speaking or in singing that they can be taught to play musical instruments, to dance, to skate and to play games, such as billiards or golf, and, as a result of teaching, can learn to perform better than they can without instruction and training. In the same way, the public argues, they should be instructed in the use of their eyes. They consult the ophthalmologist and are provided with glasses, but are given little information about the nature of their trouble or about measures which might help them to use their eyes successfully. Yet they hear of some one who went to a follower of Bates and got plenty of instruction. There are many, very many, patients who do not want to wear glasses, who would go to almost any length to escape that fate.

"...the...well-trained ophthalmologist is often ignorant of certain phases of the art and science of which he is supposed to be master. He is apt to make the mistake of arguing that because Bates's theory of accommodation is incorrect, his whole program is unsound. The history of medicine is a long list of tentative theories later proved to be erroneous, but the facts they tried to explain remain firmly established, though the theories are swept away.

"It is often pointed out that Huxley's visual acuity has not improved in any extraordinary way. He admits that. The point is that he has learned how to use what he has to better advantage. It is not the primary retinal sensation that is improved; it is the neglected, but vitally important, cerebral part of seeing that has been trained."

Beach makes a distinction between two phenomena.²⁰ The first is the skill for example, of the sailor who has been trained in the observation of marine objects. At discerning letters he is no better than the landlubber. This sort of facility, Beach claims, is acquired slowly and is permanent when once learned. Hence, these skills are distinguished from fleeting episodes of visual improvement which is the second phenomenon.

An example of the second visual acuity phenomenon, according to Beach, are the World War II Air Force student pilots who passed the visual acuity examination as a result of visual training. Under the stress of flying many lost this ability and had to be grounded. Beach's distinction, however, may be of degree rather than kind. The mariner may have had many years of experience watching the horizon while the student pilot but a few months of special visual practice.

Beach does not believe that flashes of clear vision are the result of training in observation.

"The essence of the popular courses for discarding glasses is of this transitory character. Devotees describe blinks of intensely vivid vision which they can elicit. They claim acuity at times of 20/10. They are impatient with ophthalmologists for neglecting this experience which to them is all-important. This keenness of vision may occur in one eye, and later be found to have shifted to the other eye. It may occur in both eyes. When binocular, one eye may predominate at one time, the other eye at a later time. This seems to place it on the ocular level. To be accepted as entirely due to the improved cerebral interpretation of blurred retinal images, gain in sight should (1) be a permanent skill and (2) not be found to shift from one eye to the other."

Beach believes that the eye may change its length in accommodation. His evidence consisted of 14 cases in which the visual acuity is compared without correction, "squeezing" with a one mm pinhole and finally by both squeezing and a one mm pinhole. "Squeezing" is an effort to increase visual acuity by narrowing the palpebral aperture and/or by increasing pressure on the globe similar to accidental squeezing which is fatal to cataract operations. In his experiments, about half the eyes (14) showed apparent improvement in visual acuity by squeezing but all of the cases of improvement were probably not significant, amounting to one line on the acuity chart. About 18 eyes showed further improvement in visual acuity, some of questionable significance, when a pinhole replaced squeezing. If there should be an increase of visual acuity by squeezing after the pinhole is in place, it may be reasoned that the squeezing cannot further reduce the blur circles by narrowing the palpebral fissure but must change the state of refraction of the eye. This occurred in about 15 eyes but many of the changes were of questionable significance. Furthermore, it is misleading as will be evident later to reason that a change of visual acuity must mean a change in the refractive state.

Beach concludes:

"Presumably the globe has shortened. This does not determine whether the assumed shortening of the globe is due to compression by the lids, or to influence of the extra-ocular eye muscles. Nor does it indicate whether the action of the extrinsic muscles is squeezing according to my patient or relaxation of the obliques as maintained by Bates. It is customary to deride this notion of squeezing with the extra-ocular. Yet such a possibility is not wholly fantastic. Some such action has to be assumed to explain the squeezing in cataract patients which can take place even after the lids are paralyzed by akinesis."

Beach pointed out the great subjective value to myopes of seeing clearly without glasses.

"It is customary to ridicule these sight-training exercises as a waste of time. The patient who attained the remarkable improvement by squeezing did not agree with this [probably Case 1, from 20/200 to 20/30]. He was delighted to be able to discard glasses in a number of common situations like recognizing friends on the street and reading signs. He valued it most in sailing. He pointed out that it is useful to be able to sail without having to keep wiping spray off glasses. It might be lifesaving to be able to recognize landmarks and pick up buoys if his glasses blew off. Such advantages are too real to be laughed off, and may account for some of the popularity of this system of training. Yet I understand he is likely to use his glasses much of the time."

In the discussion afterward Beach offered some strong words in defense of a refractive change causing flashes of clear vision.

"I think there is a tendency to examine great numbers of patients and find out many of them do not do anything except improve their observation, whereas, if we could devote a little time to some of these cases who do gain actual increase in acuity, and try to find out what makes them tick, we might get some sort of answer to the questions which are being asked by the persons who take these sight training courses. As a matter of fact, they are smart enough to know when they see vividly, as they do during what Bates calls central fixation, which is simply another name for these flashes that they get. They know if they see 20/10 vividly they are not getting a simple method of better distinguishing blurred images, and they are discounting statements that are made by oculists whom they feel ought to be stuffed and put in museums."

The Negative Accommodation of Yves Le Grand

Le Grand²¹ has presented evidence which indicates that some subjects are able to invoke accommodation in a negative direction. For example, a myope or an emmetrope made optically myopic with convex lenses can, in some instances, decrease his myopia with effort. Changes up to three diopters in a negative direction determined by skiascopy (taking ordinary accommodation to be positive in direction) were reported in five subjects. A summary of his results are seen in Table 1.^{21, 22}

If these results could be confirmed,* they would demonstrate the mechanism whereby myopes trained by the Bates method obtain flashes of clear vision. Furthermore, these

*There is some independent evidence which would seem to support Le Grand's finding of negative accommodation. The investigations of night ametropia of Otero and his collaborators^{23, 24} have shown that the eye has about 1.25 D. more refractive power in total darkness than with distance fixation in light. The change of power is accommodative, i.e., the result of an increase in the curvature of the crystalline lens. Since he believes that accommodation is at rest in the dark and is therefore at its zero point, Otero uses the term "negative accommodation" for the range from

results would lead one to expect that myopia of up to three diopters could be compensated for by negative accommodation much as hypermetropia may be compensated for by positive accommodation.

Table 1
Results of the Investigation of LeGrand

Subject	Age	Refractive Error (Sph.)	Negative Accommodation	Lens Before Fixating Eye	Flash Visual Acuity
A	24-26	plano	2.50	+ 4.00	20/100 to 20/67
B	24-26	plano	2.25	+ 3.00	20/100 to 20/67
C	24-26	plano	2.25	+ 3.00	20/100 to 20/67
D	24-26	- 4.00	2.75	none	20/100 to 20/67
E	> 26	- 5.50	2.75	none	20/25*

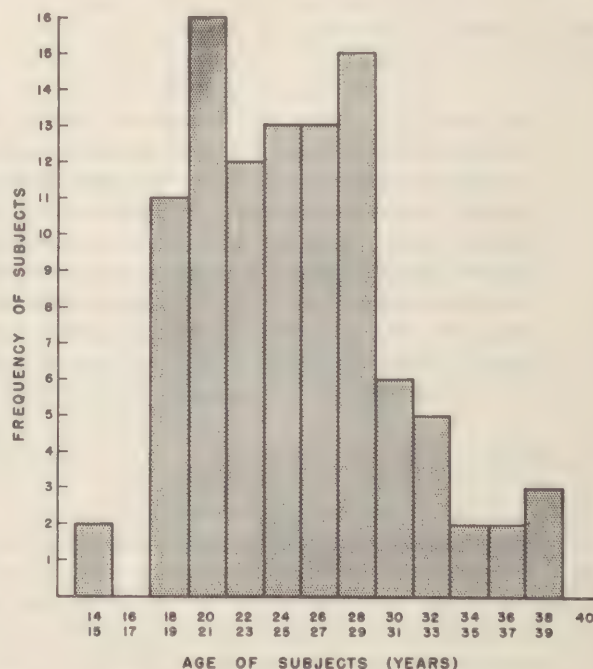
It is not to be implied that Le Grand agrees with the theories of Bates. His work merely indicates a possible mechanism which could account for some of the results claimed by Bates practitioners. Le Grand's evidence would not change the site of the accommodative mechanism from its generally accepted place, that of the crystalline lens and ciliary muscle.

At this point it seems clear that there should be an investigation which would attempt to confirm the findings of Le Grand, and determine if negative accommodation is the phenomenon which could account for the reported large increases in visual acuity which are claimed to be obtained by the myopic followers of Bates.

Incidence of Flashers

The following experiment was performed in order to get some estimate of the incidence of those people who without regard to previous training or experience could obtain unusually clear vision, despite myopia.

One hundred clinical patients between the ages of 14 and 40 years were taken at random. The distribution of age is given in Figure 1.



what is generally considered 1.25 D. to zero accommodation. Whatever the merits of Otero's view, this is not negative accommodation in the sense used by Le Grand or in this paper. An eye examined in photopia has a refractive state which is its generally accepted zero point. Increase of refractive power in scotopia is positive accommodation. The refractive power of the eye must decrease from its generally accepted zero point to exhibit negative accommodation as defined here.

Otero and his colleagues also claim to have demonstrated true negative accommodation of 1.0 to 1.5 D. in subjective experiments in which targets were viewed through a telescope. As yet there has been no confirmation of this phenomenon in their objective measurements of accommodation with Purkinje image photographs.

Also because of the definition of the zero point, the term 'negative voluntary accommodation' used by Marg²⁵ does not apply here.

It may be seen that the median age corresponds to that of Le Grand's subjects. They were refracted and a new prescription found. Those with a corrected Snellen acuity of less than 20/30 each eye as taken with a modern projector chart were rejected as subjects. The correction was put in a trial frame with a +3.00 D.S. add which blurred distance vision. Visual acuity was now taken at 20 feet with a Clason visual acuity meter. This instrument projects letters which may be varied in size while remaining in focus.

An occluder was held over the left eye and the subject was asked to read the letters as soon as he could without "squinting" or partly closing his eyelids. The size of the letters was increased until the subject could read more than half of the line presented. The same procedure was followed for the other eye and for both eyes together.

The subject was then instructed as follows:

"Please try to see if you can clear up the blurred letters which you can now just make out while you are wearing these glasses. You can try anything you wish except squinting your lids, looking by the edge of your glasses or moving closer to the chart. For example, you may try such techniques as trying to relax while remaining alert, blinking, opening your eyes widely, looking to one side of the letters, making your eyes feel as if they were about to cross, or anything else you may think of within the restrictions mentioned. You will have about five minutes in which to develop some technique to make the letters clearer and, if possible, perfectly clear.

After about three minutes the subject was informally questioned about the techniques he had tried and his estimate of his success. As long as the subject believed that he could substantially improve his acuity he was allowed to keep trying.

Visual acuity was taken again, following the same procedure as formerly. If the subject showed a significantly high visual acuity with effort he was asked to return at another time when he would be examined by skiametry and with the coincidence optometer of Fry. If the acuity was not significantly improved, the subject was dismissed.

The limit of significantly high visual acuity was based on a study of Hirsch.²⁶ He found that for myopia of 3.00 D., the upper 95% confidence limit was 20/130; that is, assuming normal distribution, only 2 1/2% of the subjects would be expected to show 20/130 or better. This is indeed a conservative limit since the Bates literature speaks freely of "perfect" sight and Le Grand found far better acuity in his subjects under conditions similar to those described below.

Results

Of the 100 subjects with the +3.00 D.S. add to their distance correction, 99 could not show a visual acuity of 20/130 or better either before or after the period of attempted improvement. Many subjects thought they were improving their visual acuity but measurements indicated little or no change.

One subject, Miss R. D., a 19-year-old university sophomore, did show a remarkable transient increase in acuity. Her correction for maximum visual acuity was as follows:

R. E. - 0.75 D.S. $\bigcirc$ - 0.50 D.C. axis 155°, 20/25
L. E. - 0.75 D.S. $\bigcirc$ - 0.50 D.C. axis 75°, 20/25

Her visual fields were normal and her zone of single clear binocular vision was slightly narrow but otherwise normal. She had never taken any training to improve her vision either alone or under supervision.

When the new prescription was combined with a +3.00 D. add to both eyes in a trial frame, the subject had a visual acuity of R.E. 20/160, L.E. 20/145, B.E. 20/145. After about five minutes of attempting to see clearly, the subject was tested again, showing R.E. 20/33, L.E. 20/33. Before both eyes could be tested together, her vision returned to the previous blurred state and no measurements could be taken by skiametry or coincidence optometry.

The subject returned in a week for another attempt but she could not flash again. Still another attempt was made a week later but without success. Hence, it was not possible to investigate the mechanism of the original flash or clear vision.

Rather than speculate on the basis of flashes from this one uninformative case, it was decided to select a group of subjects who could flash at will so that any conclusions as to the mechanism of flashes could be based on the evidence of actual measurements.

Accommodation and Flashing

Two procedures were used to obtain subjects who could meet the necessary requirements for this experiment. The first was to place a classified advertisement in the personal column of The Daily Californian, a student newspaper. The notice read as follows:

"MYOPES! Do you have "flashes" of clear vision which you can MAINTAIN at will for at least several seconds without your glasses? If so, volunteer for a scientific investigation of this phenomenon. Telephone for appointments, University of California School of Optometry, AS 3-6000, local 301 or call at appointment desk, Optometry Bldg. Please mention this announcement.

It ran for three days with an average circulation of 17,000 copies per day. About 20 persons made appointments and were given a preliminary examination.

The other procedure used to obtain this specially selected population was to request of the various Bates eye training schools or studios in the San Francisco Bay area the opportunity to examine some of their successful students. The response ran the gamut from interest and co-operation to distrust and suspicion. Three subjects were thus obtained and their data will be given presently.

Of the twenty people who responded to the newspaper announcement, most were rejected for various reasons after a preliminary examination. Some apparently came solely out of curiosity. Others found it impossible to produce a flash at will or sustain it long enough for measurement to be made. Still others could show no significantly good acuity using the 95% confidence level already mentioned for the ametropia concerned. A few could improve their vision by half closing the eyelids or putting pressure on the globe with a finger, but these were rejected. Two of the twenty did show a remarkable increase in acuity with effort and were accepted as subjects.

Results

Mr. J. H. J., age 32 years.

History: In 1943 this subject took training for the improvement of his myopia from a member and follower of the Optometric Extension Program. The subject believed that he still retained the ability to reduce his myopia with effort although not as well as originally. He claimed that he could read 20/25 without glasses at one time.

The following prescription was found to give maximum acuity.

R. E. - 2.50 D.S. $\bigcirc$ - 0.50 D.C. axis 67° , 20/20
 L. E. - 3.25 D.S. $\bigcirc$ - 0.25 D.C. axis 170° , 2/20

Without lenses he exhibited 20/200 acuity in each eye and with both eyes together. With effort, visual acuity was increased to 20/50. The skiascope did not indicate any change of power before or after acuity was changed. Measurement was then made with the coincidence optometer of Fry. This instrument, which works on the Scheiner double pinhole principle, was introduced to the eye from the side through a half-silvered mirror which allowed a Snellen chart to be seen. Thus, the subject could make a vernier setting of the optometer images while fixating the Snellen chart. Five readings were taken with normal vision and the mean was found. Then five readings were taken with flash vision and they were averaged. The means and their difference are recorded in Table 2. The t test for the difference between means when the groups are correlated²⁷ showed that the value was not significant at the 95% confidence level.

Table 2

Experimental Results

Refractive state determined from mean of five readings of the coincidence
 optometer of Fry.

Subject	Normal Vision D.	Flash Vision D.	Difference	t*	P	Visual Acuity naked eye Normal	Flash	Expected D. changes for the acuity difference	Age
Mr. J. H. J.						20/200	20/50	1.37	32
L.E. occluded	3.70	3.92	- 0.22	2.76	<.05				
B.E. fixating	3.84	3.71	+ 0.14	.78	<.05				
Miss S.S.	5.23	5.43	- 0.20	.54	<.05	20/200	20/70	1.12	19
Miss E.F.	5.77	5.56	+ 0.21	1.88	<.05	20/200	20/50	1.37	13
Mr. J.Y.	5.17	5.37	- 0.20	2.62	<.05	20/400	20/50	2.63	26
Mr. J.B.	7.14	6.87	+ 0.27	1.75	<.05	20/300	20/60	2.00	39

*Based on the difference between the means of two groups of five readings each. Four degrees of freedom.

In order to see the effect of binocular relative to monocular fixation, both were used with this subject. The right eye fixating alone showed -0.22 D. (change in the myopic direction) which was not significant at the 95% level. With both eyes fixating, the right eye measured +0.14 D. change (in the opposite direction) which is also not significant.* These two measurements were taken on different days.

*To avoid any possible confusion it should be stated that the minus sign is used to indicate positive accommodation which increases the power of the eye, in the direction of myopia. Contrariwise, the plus sign identifies negative accommodation which decreases the refractive power, in the hypermetropic direction. The signs represent the type of correction lens which would neutralize the accommodation.

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From the increase of visual acuity alone one would expect a negative accommodation of about +1.37 D.

Miss S. S., age 19 years.

History: When she was 12 years old, this subject took Bates training and she was able to get flashes easily. She stated that she could no longer get flashes as well as formerly.

The following prescription was found to give maximum visual acuity.

R.E. -4.75 D.S. $\odot$ - 0.50 D.C. axis 75° , 20/15
L.E. -5.00 D.S. , 20/15

Without lenses, the acuity was, R.E. 20/400 and L.E. 20/200. However, with effort (and initially using a "long swing") the subject was able to read 20/70 slowly. Skiametry of the right eye while the left eye fixated showed no change of refractive power from before the flash to after the flash had occurred.

On the coincidence optometer, five readings of the refractive state of the right eye were taken with normal vision and averaged. Then five readings were taken during flashes of clear vision and averaged. As may be seen in Table 2, the subject showed -0.20 D. change of refractive power with flashes (the minus sign signifies that the change is in the myopic direction). The increase in power was not statistically significant at the 95% confidence level. To account for the increase of visual acuity a change of about +1.12 D. would have been expected.

Three subjects were obtained from the office of a practitioner of the Bates technique.*

Miss E. F., age 13 years. R.E. 20/400, L.E. 20/200, B.E. 20/200.

A subjective refraction yielded the following:

R.E. -5.50 D.S. $\odot$ -0.50 D.C. axis 180° , 20/20
L.E. -5.25 D.S. , 20/20

With time and effort the visual acuity without glasses was raised to 20/50. Again there was no skiascope indication of a change in the refraction.

The coincidence optometer indicated a change of only +0.21 D. as may be seen in Table 2. This change of power was not statistically significant at the 95% level. It would have taken about +1.37 D. change to account for the increased acuity on the basis of retinal image sharpness.

Mr. J. Y., age 26 years. R.E., L.E., and B.E., 20/400.

A subjective refraction showed the following:

R.E. -4.75 D.S. $\odot$ -0.75 D.C. axis 90° , 20/15+
L.E. -4.75 D.S. $\odot$ -0.75 D.C. axis 90° , 20/15+

When this subject attempted to see clearly, he could read 20/50 with his naked eyes. No indication of a change in the refractive state was to be found with the skiascope. A

*We are grateful to Mrs. Beatrice Clarke of the Berkeley Studio of Eye Education and to Mr. James Yandel for their co-operation in obtaining these subjects.

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change of -0.20 D. was found with the coincidence optometer as may be seen in Table 2. The change, as indicated by the minus sign, was in the myopic direction. The statistical significance of this change is below the 95% level. The change did not attain the expected $+2.63$ D. if the increase of acuity is to be attributed to negative accommodation.

Mr. J. B., age 39 years. R.E. 20/400, L.E. 20/300, B.E. 20/300.
This subject had a refractive error of the order of seven diopters of myopia but he was not available for a full subjective refraction.

The skiascope showed no change of refractive state when the subject attempted to read 20/60 and succeeded. The optometer showed $+0.27$ D. (change in the hypermetropic direction) without statistical significance at the 95% level. This small value is not great enough to explain the large increase in visual acuity on the basis of a sharpening of the optical image on the retina. It would require about a $+2.00$ D. change in this case.

Discussion and Conclusions

From the results of the experiments reported here, one would not expect to find more than one person in a hundred capable of flashing without some special training.

It was further demonstrated that in all five specially selected subjects who could flash there was no change in the refractive power of the eye which could account for the increase of visual acuity. Changes in the dioptics of the eye ranged from $+0.27$ to -0.22 D. and none were statistically significant. Even the largest positive change (a decrease of refractive power) was not large enough to account for the great improvement in visual acuity (20/300 to 20/60).

The quality of the visual acuity was not as good as one would expect from the Snellen fractions given. It is frequently a slow process to get a flash and there was usually some stumbling over the letters. In the investigation of the five flashers, visual acuity was measured with a chart which was not familiar to the subjects. It was noted that familiar charts similar to the ones the flashers had practiced on gave better vision than 20/50.

Several questions arise regarding the increase of acuity exhibited by flashers. First what is the mechanism of the flash? All that can be said at this time is that the experimental evidence offered here indicates that there is no change of refractive power of the eye which is large enough and in the proper direction to provide a refractive basis for a flash. In other words, there is no evidence of a negative accommodation except perhaps in insignificantly minute and uncontrollable amounts. It would seem that unless the phenomenon is attributable to extraordinary optical aberrations of the eye, for which there is no evidence, the increase in visual acuity exhibited by flashers must be central to the retinal image, i.e., in the physiological or perceptual image. The phenomenon seems similar to that of apparent accommodation in aphakia where no change of refractive power of the eye has been found^{4,5}. It is likely that the perceptual image is improved by training and by the temporal accumulation of information by the visual apparatus during some of the ritual of swinging, blinking, etc. There is also presumably a better organization with time of the information which goes to make up the perceptual image.

Another question involves the retention of the skill of flashing. Most subjects were apologetic about the quality of their flashes, explaining that at one time they could clear up everything perfectly but at present the flashes were poor because of a lack of practice. Actually even the best subject could read no better than 20/50 with an unfamiliar chart. It appears that the Bates techniques are therefore limited both as to retention of the skill and to its ability to provide "perfect sight" even for short periods of time.

There are some further interesting points that should be mentioned. Although the

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visual acuity during a flash may not be better than 20/50, the subjective experience of the flasher is that he is seeing more clearly than he has ever seen with glasses that correct him to a visual acuity of 20/15. As Scholz¹² has said:

"When you get a flash of perfect sight, you know it, it is a revelation.

"Every flash convinces you more of the fact that there is nothing wrong with the eye itself, and this conviction, increasing patience and confidence, helps the treatment a good deal.

[italics mine]

It is this strong introspective but psycho-physically erroneous evidence that helps keep the Bates technique alive.

Other interesting subjective phenomena are reported. The flasher may feel his flash of clear vision shift from its locus in one eye to the other or back again. He may feel a burning or stinging sensation in his corneas during flashes as if sand or wind had blown into his eyes. He may have illusions of form such as seeing a fan-like distribution of the letter he is trying to read. It merges and the letter becomes clear. These are but a few of the more generally reported phenomenological observations.

As a final word, the Bates and other similar visual training techniques should not be dismissed entirely. There are conceivable uses for them by those who will not or cannot wear optical corrections for their vision, or by those, such as Aldous Huxley where no optical device or orthodox treatment will help.

Summary:

The claims and counterclaims of Bates practitioners and orthodox eye specialists have been reviewed in detail. Particular attention has been given to the report of negative accommodation by Le Grand which could provide a basis for some of the claims of the Bates school.

Two experiments were performed. A hundred clinic patients between 14 and 40 years of age were measured for visual acuity wearing their newly found prescription combined with a +3.00 D. S. lens before each eye. Then after instructions on how to see more clearly followed by a short practice period they were again measured. Only one subject of the hundred demonstrated unusually good transient acuity (a flash) but she was unable to maintain it or repeat it for measurement of refraction. This experiment indicated that "flashers" (those who can obtain remarkably large transient increases in visual acuity) are uncommon.

The next experiment consisted of five specially selected subjects who could flash. Some of them were undergoing Bates training at the time. Visual acuity was improved from around 20/200 to 20/50. The refractive state of the eye was measured by skiametry at one time and with the coincidence optometer of Fry at another. No change in power was found by skiametry from normal to flash vision. The optometer indicated changes of -0.22 D. to +0.27 D. none of which were significant at the 95% confidence level. For the changes in acuity to be attributable to negative accommodation, the dioptric change would need to be from about plus one to two and a half diopters, depending on the subject.

The finding of negative accommodation by Le Grand could not be confirmed.

It is suggested that the Bates method improves the perceptual image by training interpretation of blurs, and by the accumulation of visual information during the relatively long time required for the eliciting of flashes.

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The introspective feeling not borne out by measurement of a clarity during flashes greater than that experienced when allowed to have 20/15 vision with glasses is an important factor in explaining the popularity of the Bates school.

The Bates method and other similar visual training techniques have conceivable uses, but they are no substitute for helpful optical corrections of the eyes.

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Since this paper was written, it has been brought to the writer's attention that an article entitled "Variable Acuity" by James R. Gregg has appeared in an unabridged journal (*Jour. Amer. Optom. Assn.*, 18, 432-435, March 1947). The results of this paper essentially agree with the data presented here in relation to the increase of visual acuity and the lack of change of accommodation as measured by skiametry. Two of the three subjects had a very low degree of myopia and were able to flash to 20/20. The third subject who was a myope of about -4.50 D. could flash only to 20/50.

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Discussion:

- Dr. Mote commented on the possible similarity of Col. Marg's results and the results of conditioning experiments in which subjects can condition such ordinarily voluntary actions as constriction of the pupil. Dr. Mote suggested that possibly some kind of conscious conditioning went on in Col. Marg's experiments.
- Col. Byrnes commented that the question of "flashes" of clear vision reminded him of another phenomenon which no one has explained. If one observes a propeller rotating at 400-500 revolutions per minute, occasionally one can get a clear view of one blade of the propeller, appearing to stand still in front of a rotating propeller.
- Dr. Tousey suggested that Col. Marg's results might be related to pupillary restriction. If the pupil constricted suddenly, there might be an increase in visual acuity.
- Lt. Col. Marg replied that he had observed the pupils of his subjects during the experimentation and had never observed a pupillary constriction coincident with the "flash" of clear vision.
- Dr. Shahan commented on the general evaluations of the Bates method made at Johns Hopkins University and Washington University. It was found that in some 10-15% of the cases of myopia, improvement occurred with training. These cases appeared to have worse acuity before improvement than one would expect on the basis of their refractive error.
- Lt. Col. Marg reported that all five subjects in his experiment were interested in getting rid of their glasses. They really wanted to improve their acuity. Col. Marg stated that he does not believe subjects like this have been used in every experiment.
- Dr. Fry stated that he had one suggestion to make. Dr. Fry suggested that the test objects which were used in Col. Marg's experiment are ones for which there is a possibility of improvement due to an increased ability to interpret blurred images. Experiments involving test objects which are less subject to this kind of interpretation might fail to show the "flashes".
- Dr. Fry suggested that future experiments should attempt to ascertain whether the improvement is due to improvement of the image or some other factor. One method of determining whether the image quality is improved in the "flashes" would be to infer image blurredness from test objects such as those utilized by Fry and Bartley.
- Dr. Shahan asked whether the "flash" could be due to a momentary dry spot on the cornea or presence of a foreign body on the cornea. Either of these effects might result in an improvement in refractive error due to change in the refractive index of the cornea.
- Lt. Col. Marg pointed out that this explanation is inadequate since his experiments showed that there was no change in refractive error at the instant of the "flash".
- Dr. Fry pointed out that the instrument utilized by Col. Marg to measure the refractive error, the Fry Optometer, samples only a small portion of the optical system of the eye so that there could be a refractive error change due to drying at some point on the cornea which would not appear in measurements with the optometer. Dr. Fry suggested that a keratoscopic examination of the entire cornea should be made during the instant of the "flash".
- Dr. Tousey suggested that the subject had habits of excessive accommodation so that, with relaxation of the excessive accommodation, acuity could be improved. The subjects might have become practiced at momentary relaxation of the excessive accommodation and thus obtained the "flash".

Lt. Col. Marg repeated that such an explanation is inadequate since measurements with the Fry Optometer did not demonstrate any changes in accommodation concurrent with the "flash".

BIBLIOGRAPHY ON VISIBILITY

The Navy Research Section of the Library of Congress has just completed a bibliography on Visibility, which covers the published literature from 1925 to 1950. It consists of 2,008 references arranged by a subject classification, covering the following:

- I. Visual detection factors in the laboratory.
- II. Physical variables in the field.
- III. Field visibility computations, measurements, and observations.
- IV. Engineering applications of visibility data.

It is expected that the bibliography will be published shortly and copies will be available to members of the Committee, the various agencies of the Armed Forces and contractors working in the field of visibility.

The Navy Research Section is now working on the report literature in this field, and this will cover both classified and unclassified reports. Consequently it will appreciate the assistance of any members of the Committee who have copies of such reports or know of any that have been issued. This would include those of foreign origin, such as British and German. Such information should be mailed to:

Dr. Clement R. Brown, Head
Science Bibliography Unit
Navy Research Section
Library of Congress
Washington 25, D. C.
(Repeat address)

The Navy Research Section is in a restricted area and Dr. Brown and his staff are cleared to receive security information through Secret.

THE INHERENT CONTRAST OF SUBMERGED OBJECTS

Seibert Q. Duntley

The visual detectability of any object submerged in deep water depends upon its inherent contrast. This, in turn, depends both upon the reflectance of the object and upon the lighting conditions within the water. It is the purpose of this paper to discuss those special features of the distribution of light within the sea which govern the inherent contrast of submerged objects.

It will be useful to consider first the case of diffuse illumination at the surface of the sea from a substantially uniform sky. The water will be considered "infinitely deep" in the sense that no radiometric quantities at the target or at lesser depth would be affected if the water were deeper.

Consider any horizontal plane P at depth d beneath the surface of the sea. The layer of water between P and the surface will have reflectance R and transmittance T. Both R and T will depend upon the wave length of the light used. The following discussion must be regarded, therefore, as strictly applicable to monochromatic light only, although it has been found in practice that the sea is sufficiently non-selective throughout the visible spectrum that equations (3), (4), (5) and (6) of this paper are usefully applicable to photopically measured luminous quantities. Experiment, moreover, shows them to be applicable also on sunny days.

Let the downward irradiance on the surface of the water be H_0 , and let t_1 represent the transmittance of the water surface. The downwelling irradiance H_D on the top surface of plane P would be $H_0 t_1 T$ if no interreflections took place, an infinite series of interreflections occur, however, between the surface of the water and the layer above the plane P. These increase H_D by a factor $(1 - r_2 R)^{-1}$, where r_2 is the "emergent reflectance" of water for diffused flux (see Duntley, S. Q. J. Opt. Soc. Am 32, 65[1942]). Additional contributions to H_D arise from light which, having passed through the plane P, is reflected by the deeper water (R_∞). This light initiates an infinite series of interreflections between the waters above and below plane P and further interreflections occur between the water surface and the water. All of these interreflections may be summed as follows:

$$H_D = H_0 t_1 T (1 - r_2 R)^{-1} \sum_{j=0}^{\infty} [R R_\infty + r_2 R_\infty T^2 t_1 (1 - r_2 R)^{-1}]^j$$

or

$$H_D = H_0 t_1 T [(1 - R R_\infty) (1 - r_2 R) - r_2 T^2 t_1 R_\infty]^{-1} \quad (1)$$

The upwelling irradiance H_u on the lower surface of plane P is also affected by interreflections. Infinite series of these arise from the same causes described above in connection with H_D . The complete expression for H_u may be written;

$$H_u = H_0 t_1 T (1 - r_2 R)^{-1} R_\infty \sum_{j=0}^{\infty} [R R_\infty + r_2 R_\infty T^2 t_1 (1 - r_2 R)^{-1}]^j$$

or

$$H_u = H_0 t_1 T R_\infty [(1 - R R_\infty) (1 - r_2 R) - r_2 T^2 t_1 R_\infty]^{-1} \quad (2)$$

Comparison of equations (1) and (2) shows that:

$$H_u = R_\infty H_D \quad (3)$$

Equation (3) indicates that the ratio of upwelling irradiance to downwelling irradiance is a constant characteristic of the water, but independent of depth, i.e. $H_u/H_D = R_\infty$. It follows that if a flat matte horizontal surface has a reflectance $R_O = R_\infty$, its apparent radiance $N_O = R_O H_D$ will match that (N_B) of the deep-water background beneath, since $N_B = H_u$ in flux units. Such a surface is said to have zero inherent contrast for a downward-looking observer; the surface will be invisible regardless of its depth.

If N_O differs from N_B an inherent contrast C_O will exist. Let C_O be defined by the relation:

$$C_O = \frac{N_O - N_B}{N_B} \quad (4)$$

Thus:

$$C_O = \frac{R_O H_D - H_u}{H_u} = \frac{R_O - H_u/H_D}{H_u/H_D}$$

or

$$C_O = \frac{R_O - R_\infty}{R_\infty} \quad (5)$$

The inherent contrast of a submerged matte horizontal surface is shown by Equation (5) to depend only upon its reflectance R_O and upon R_∞ for the water; inherent contrast does not depend upon the depth of the object.

If the observer does not observe the surface perpendicularly, equation (4) still defines the inherent contrast, but Equation (5) does not apply because $N_B \neq H_u$. In such a case, data on the directional variation of N_B must be obtained.

If the reflecting surface is not horizontal, but is viewed perpendicular to its surface, inherent contrast will be given by:

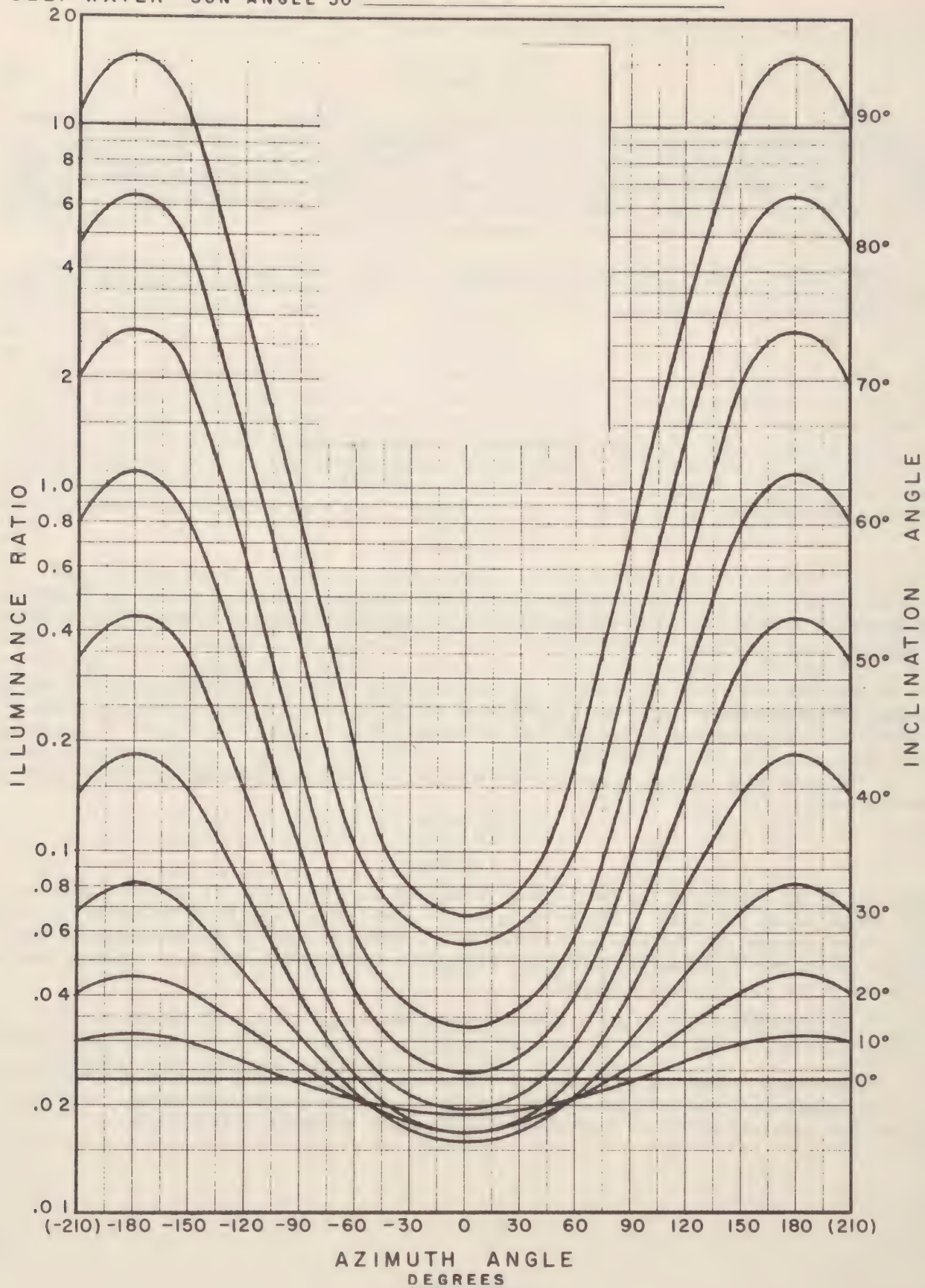
$$C_O = \frac{R_O - H_1/H_2}{H_1/H_2} \quad (6)$$

Where H_2 is the irradiance on the surface facing the observer, and H_1 is the irradiance which would reach the plane of the surface on the side facing away from the observer if no object were present. H_1/H_2 has been called the "irradiance ratio". An analogous quantity E_1/E_2 , called the "illuminance ratio" can usefully be employed to calculate inherent contrast by means of the approximate relation:

$$C_O = \frac{R_O - E_1/E_2}{E_1/E_2} \quad (7)$$

An automatic recording photoelectric photometer for measuring illuminance ratio E_1/E_2 has been constructed and used at sea off Key West, Florida and off San Diego, California. Typical data obtained with this instrument are shown in Figure 1.

DEEP WATER SUN ANGLE 30°



RESTRICTED

Discussion:

Mr. Middleton asked if Dr. Duntley had any particular reason for departing from the traditional geophysical practice with respect to the zenith angle and the elevation angle.

Dr. Duntley stated that he did not particularly care which usage was employed.

MEASUREMENTS AND ESTIMATES OF SKY BRIGHTNESS
FOR ALL ALTITUDES OF THE SUN FOR VARIOUS ALTITUDES
OF THE OBSERVER ABOVE THE SURFACE OF THE EARTH

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The attenuation coefficient of air for daylight viewed with the light adapted eye is denoted by β . β is defined by

$$i = i_0 e^{-\beta x}, \quad (1)$$

where i_0 and i are the intensities of a collimated beam of light entering and emerging from a layer of air x km in thickness at 1 atmosphere pressure. Therefore throughout this paper the unit of β is reciprocal km of air reduced to 1 atmosphere pressure. The attenuation of the atmosphere for visible light is due almost entirely to scattering, with negligibly small true absorption. For pure air molecules which scatter according to the Rayleigh theory¹

$$\beta = 0.0126 \text{ km}^{-1} \quad \text{Rayleigh air.}$$

Experiment has shown^{1, 2} that for air from 10,000 to 38,000 feet β is about 0.019 km^{-1} . When the air above 10,000 feet has this value of attenuation it is defined to be "clear".

$$\beta = 0.019 \text{ km}^{-1} \quad \text{Clear air above 10,000 feet.}$$

It seems probable that for altitudes below 50,000 feet values of β greater than 0.019 are more probable than values of β less than 0.019.

Astronomers in observatories situated on mountains or high land have often used a value of 90 per cent for the vertical transmission of visible light through the entire atmosphere, or one air mass, for a clear atmosphere. One air mass is equivalent to 8 km of air at STP. Then β is 0.105 per air mass or $0.105/8 = 0.0131 \text{ km}^{-1}$ on an average. This is nearly the Rayleigh value for "pure" air, and is a lower value than is found for "ordinary clear" air. The vertical transmission of "ordinary clear" air observed in open country, no desert, is around 70 per cent, which gives $\beta = 0.3$ per air mass or 0.0375 km^{-1} on an average. But in the present discussion something more detailed than an average value is needed, because of the 0.3 an amount $0.3 - 0.0126 \times 8 = 0.1992$ is due to haze in the air (neglecting an amount about 0.02 due to ozone in the upper atmosphere). There is usually more haze near the surface than there is at high altitudes. The distribution of haze with altitude has seldom been measured; it is of course a very erratic and variable quantity.

To fix ideas the atmosphere described in Table A is suggested as a "Standard ordinary clear atmosphere". The atmosphere of Table A has a vertical transmission of 70 per cent. In order to visualize the atmosphere the meteorological range or horizontal visibility v was calculated from the relation $v\beta = 3.92$, and is given in the third and fourth columns of Table A.

TABLE A. Standard ordinary clear atmosphere.

Altitude	β	Horizontal visibility v	
0 to 3,000 feet	0.12 km^{-1}	33 km	20 statute miles
3,000 to 6,000	0.09	43	27
6,000 to 10,000	0.05	70	43
10,000 to 50,000	0.019	206	128
50,000 to 100,000	0.0126	319	198

The horizon, or the "true" horizon as it is sometimes called, is the horizontal plane passing through the eye of the observer. The "horizon of the observer" is defined geometrically to be the circle formed by the locus of points of tangency of the cone which is tangent to the surface of the earth and whose apex is at the eye of the observer. Whether the observer can actually see his horizon or the true horizon depends upon the amount of haze and clouds. On the surface of the earth the observer is approximately in the plane of his horizon. When the observer is at an altitude h km above the surface of the earth his horizon is depressed below the true horizon by an angle d where

$$\cos d = r/(r + h), \quad (2)$$

$r = 6360$ km being the radius of the earth. For heights below 100,000 feet or 30.5 km h is small with respect to r , and (2) becomes approximately

$$d = (2h/r)^{\frac{1}{2}}, \quad (3)$$

Table B was calculated from (2) and (3) and shows that for h below 50,000 feet d is less than 4° . In (2) and (3) atmospheric refraction is neglected. This may be put in by a method due to Sweer³ and leads to values of d a fraction of a degree less than those of Table B.

TABLE B. Depression angle of horizon.

H	d
0 feet	0°
10,000	1.8°
20,000	2.5°
30,000	3.0°
40,000	3.5°
50,000	4.0°
70,000	4.9°
100,000	5.7°

The "upper hemisphere" of the observer's scene is the portion of the sky above the observer's horizon. It is approximately a hemisphere when the observer is on the surface and becomes greater than a hemisphere as the observer rises above the surface. The "lower hemisphere" of the observer's scene is the portion of his scene below his horizon. It is approximately a hemisphere when he is on the surface and becomes less than a hemisphere as he rises above the surface.

The following quantities are defined:

- B brightness of the point in the sky in candles per square foot;
- H altitude of the sun, positive and negative above and below horizon, respectively;
- P altitude of the point in the sky under observation, positive and negative above and below horizon, respectively;
- Z bearing of the point in the sky relative to the sun;
- ϕ is the angle between the sun and the point in the sky; it is the "scattering angle" and is related to H, P and Z by $\cos \phi = \sin P \sin H + \cos P \cos H \cos Z$.

DAY SKY BRIGHTNESS, UPPER HEMISPHERE

Tousey and Hulburt¹ measured B during a number of daytime flights during clear weather in an airplane at 10,000 feet in the Maryland area. They worked out a theory which assumed that the law of light scattering with angle ϕ was that of Rayleigh. When β was put equal to 0.019 km^{-1} , and hence, greater than the Rayleigh value 0.0126 km^{-1} , the theory agreed with the observations for $\phi > 40^\circ$. For $\phi < 40^\circ$, i. e., the sky near the sun, the observed values of B were greater than the theoretical values. This indicated that the air above 10,000 feet, even during the clearest weather in which the flights were made, contained a small amount of scattering impurity composed of particles larger in diameter than the wavelength of light.

It may be mentioned that Tousey and Hulburt used $\beta = 0.017$ and a solar illumination $i_0 = 13600$ foot candles. It later seemed probable (see Ref. 2, page 477) that i_0 may be 12,000. Using $i_0 = 12,000$ f. c. called for a compensatory proportional increase in β from 0.017 to about 0.019 km^{-1} . This occasioned no important changes in the theoretical calculations because, for the small values of β encountered, the product βi_0 appeared in the formulas.

The theoretical table for an altitude of 10,000 feet and $\beta = 0.019$ is given in Table 1. The table agrees with observations for points in the sky more than 40° from the sun, $\phi > 40^\circ$. For points in the sky less than 40° from the sun, $\phi < 40^\circ$, a correction c to the values of Table 1 must be added. The correction c for altitude 10,000 feet is given in the second column of Table 2. In Table 1 the values of B for points in the sky within 10° of the sun are marked with parentheses, for these values have no experimental foundation. Since the theoretical calculations were not carried through for P less than 10° , the values of B of Table 1 around the horizon $P = 0^\circ$ were obtained by adaptation and extrapolation from the measurements of Packer and Lock² at 18,000 feet.

Packer and Lock² made many measurements of B from an airplane at various altitudes from 18,000 to 38,000 feet. They found that their observations agreed with the values of Table 1 when the latter were reduced according to the reduced pressure at the higher altitudes and when experimentally determined values of c were added to B for $\phi < 40^\circ$. Table 2 gives the values of c smoothed, extrapolated and adjusted from their Figure 9.

Therefore, the following rules may be given for calculating B which agree with observation from 10,000 to 38,000 feet, and which therefore, may be used with some confidence up to at least 50,000 feet:

- Rule 1. Calculate B at any altitude for all places in the sky except $P = 0^\circ$ by means of Table 1 noting that B is proportional to the pressure. For convenience the pressure ratios of various altitudes are listed in Table 3. (This Table is the same as Table 6, Ref. 5.)
- Rule 2. For $\phi < 40^\circ$ add the correction c for large particle scattering from Table 2; for $\phi > 40^\circ$ the correction is zero.
- Rule 3. At the horizon $P = 0^\circ$ use the values of Table 1, without change for all altitudes.
- Rule 4. For values of P between 0° and 15° adjust B somehow to be consistent with rules 1, 2 and 3.

The reason for using the theoretical Table 1 instead of the observed values may now be understood. It is merely because the observed values covered only a limited number of places in the sky and altitudes of the sun, and were therefore, in no sense complete; they could not be made complete within the practical limitation of the flight programs. Since the theoretical Table 1, with the correction Table 2, agreed with what observations were made, it could be extrapolated and interpolated with some confidence to fill in the gaps left in the experimental program and to yield a complete pattern of the facts.

It should be stated that Rules 3 and 4, which give a method for getting values of B at and near the horizon, are based on few observations. Such values are probably quite variable being sensitive to the haze and cloud conditions of the atmosphere.

Experiment and theory^{1,2} indicated that snow or a complete cloud cover below the observer increased B by about 30 per cent.

There appears to be no theoretical reason why Table 1 and the Rules should not give approximately correct values of B to heights above 38,000 feet where there are no observations of B but where the pressures are known. As a matter of fact Teele⁴ measured B for $P = 38^\circ$ during the ascent of the balloon "Explorer II" to an altitude of 72,395 feet, and concluded that B was proportional to the pressure up to this height. But since he omitted to consider the changing altitude of the sun during the ascent, his data must be reworked before it is clear what they indicate.

For values of B from 10,000 feet down to the surface the theoretical Table 1 with the Rules can be used. Actually there are available observed values of B at the surface; these are summarized in Reference 5. And, if desired, the directly observed values of B at the surface can be used instead of the values calculated from Table 1.

It is true, as indeed was to be expected, that the observed series of values⁵ at the surface, one series at Washington, D. C., one at Davos, Switzerland, and one at Bocaiuva, Brazil, differ from each other by amounts varying up to 100 per cent. It happens that the values derived for the surface from Table 1 and the Rules fall among the observed values and may therefore be said to agree with them. This agreement is more or less chance and would not necessarily be expected, because β at the surface was certainly greater than 0.019 used in Table 1. The explanation of the agreement seems to lie in the fact that β enters twice into a calculation of B in a compensatory manner; for example, an increase of β reduces the intensity of rays of light entering each elementary volume of air, but at the same time increases the light scattering of the volume. Hence, a calculation of B based on too low a value of β may (and does) give an approximately correct value.

DAY SKY BRIGHTNESS, LOWER HEMISPHERE

The only observations available at this laboratory of B for the lower hemisphere are five measurements of Packer and Lock. These were taken casually, and it is hardly fair to lift them out of their note book. Anyhow, they are given in Table C:

TABLE C. Lower hemisphere day values of B.

Altitude of Observer (feet)	H	Z	P	B ca. ft. ²	Terrain in line of sight
15,000	42°	90°	-30°	260	farmland, no clouds
15,000	42°	90°	-15°	372	desert, no clouds
15,000	42°	90°	-15°	1500	clouds
20,000	40°	100°	-15°	357	desert, no clouds
20,000	40°	100°	-15°	452	desert, no clouds

It is seen from these data that, except for the case of clouds in the line of sight, B in the lower hemisphere was 1.5 to 2 times as bright as a similarly placed point in the upper hemisphere.

Although no attempt will be made here to work out theoretical values of B for the lower hemisphere one can get a numerical feeling for the problem by considering a maximum and minimum case. Suppose that the sun were directly overhead, that the surface of the earth were a perfect lambert surface of diffuse reflectivity 100 per cent (as might be approximately for fresh snow or complete smooth cloud cover), and that there were no atmosphere between the observer and the surface. Take $i_0 = 12,000$ foot candles for the solar illumination. Then

$$B = 12000/\pi = 3700 \text{ ca. ft.}^{-2}, \quad (4)$$

and is constant over all directions of the lower hemisphere and at all heights above the surface. This is a maximum value of B (omitting such special optical cases as shine of water and sheen of vegetation).

A minimum value for this case is obtained if a 6 per cent diffuse reflectivity for the surface of the earth were assumed (as for a moderately thick forest of evergreens). Then for $H = 90^\circ$, $i_0 = 12000$ f.c., one has

$$B = 0.06 \times 12000/\pi = 222 \text{ ca. ft.}^{-2}$$

and again B is constant over all directions of the lower hemisphere and at all heights above the surface, since no atmosphere is assumed.

The actual values of B of the lower hemisphere for the sun in the zenith $H = 90^\circ$ will be between the values 222 and 3700 ca. ft.⁻² (and between these values multiplied by $\sin H$ for other values of H), and will depend upon the state of the atmosphere, such as the amount of haze and clouds, and the altitude of the observer. Thus, it can be understood (as is obvious and well known) that for certain states of the atmosphere and of the surface of the earth, and for certain altitudes of the observer and places in the sky the lower hemisphere is darker than the upper atmosphere, and for other conditions and other altitudes of the observer is brighter than the upper hemisphere.

This is as far as we shall go with the problem at present. A large advance into the problem can be made theoretically and further measurements can be made, but before doing this it seems better to wait until the problem is clarified. It would of course be valuable to know if other measurements exist of B for the lower hemisphere.

TWILIGHT SKY BRIGHTNESS, UPPER HEMISPHERE

In 1951 two series of measurements of the brightness of the twilight sky in clear weather were made by Koomen, Lock, Packer and Scolnik⁶ of this laboratory. A recording photoelectric photometer of 1.5° field of view was used, calibrated to read candles per square foot against a non-selectively attenuated source at a color temperature of 2350° Kelvin which ranged in brightness over nine orders of magnitude from that of the daylight sky to that of the night sky. By means of a greenish filter on the photometer the spectral sensitivity curve was that of the light adapted eye. With this calibration the photometer was used to read, or to give numbers to, the brightness of all points in the twilight sky during all the color change from daylight to yellow, pinkish, greenish, etc., and to full night.

The two series of twilight sky measurements for the upper hemisphere in clear weather are given in Tables 4 and 5, one made at Sacramento Peak, New Mexico, altitude 9200 feet, and the other at a station in Maryland, altitude 100 feet. The measurements were made for solar altitudes from $+5^\circ$ to -15° , and therefore, nearly to full night conditions which set in at about $H = -18^\circ$. It may be seen from Tables 4 and 5 that near the horizon the Sacramento Peak sky was of about the same brightness as the Maryland sky, and for places in the sky above 10° , i.e., $P = 10^\circ$, the Sacramento Peak sky was about $2/3$ to $1/2$ of the brightness of the Maryland sky. This difference indicated that there was slightly more haze in the clear Maryland sky than in the clear Sacramento Peak sky, which seemed reasonable.

When the two Tables 1 and 4 are compared at $H = 5^\circ$ where they overlap, it is seen that the values of B taken from an airplane at 10,000 feet in the Maryland area (Table 1) are about $2/3$ of the values of B taken at 9200 feet on Sacramento Peak (Table 4). The two sets of measurements were taken 11 years apart and with different types of instruments. Whether the difference is due to this or to a difference in the air at the two places cannot be said. If one is interested in making smooth computations for about 10,000 feet based on Tables 1 and 4 one can smooth these two tables together; this has not been done. Or, if in such computations an inaccuracy in B of 50 per cent is not important, one can use the values from either table.

To get values of B for the upper hemisphere for altitudes of the observer from the surface to 10,000 feet one can interpolate between Tables 4 and 5. However, since these tables have not been smoothed, one with respect to the other, one will find that such interpolations will be full of small and unimportant inconsistencies.

To get values of B for the upper hemisphere for altitudes of the observer above 10,000 feet use the values of Table 4 without change, keeping in mind that H is the altitude of the sun above the true horizon. The reason that B during twilight remains constant, at least to a first approximation, as the altitude of the observer increases is a theoretical one and is to be found from an examination of the theoretical curves of Figure 10, Reference 7. In that figure it is shown that for the zenith sky the light comes almost entirely from levels in the atmosphere above 30 km (90,000 feet) for H from 0° to -7° ; even for $H = -9^\circ$ more than $1/5$ of the zenith sky light comes from scattering in levels above 10 km (30,000 feet). Hence, as the observer rises upward from 10,000 feet he does not pass through any illuminated atmosphere (to a first approximation) and therefore, the sky in his zenith does not change in brightness very much. A similar argument can be given for other places in the sky. Near the horizon, particularly toward the sun, the argument may be faulty. But there are no measurements of B at high altitudes during twilight with which to test the argument.

RECEIVED TWILIGHT SKY BRIGHTNESS, LOWER HEMISPHERE

There are no measurements of B for the lower hemisphere during twilight and the optical situation seems so complicated that one hesitates to attempt to complete theoretical calculation. A few approximate estimates can be made. For this purpose we refer to the measurements of the brightness B_w of a white horizontal diffusing plaque exposed to the upper hemisphere of the sky during twilight at Sacramento Peak⁶. The observed values of B_w are in column 2, Table D; for comparison similar values measured by Kimball⁸ in 1916, at Washington are in column 3, Table D. (It may be pointed out that B_w need not be measured but can be calculated by suitable integration of the values of B over the upper hemisphere of Table 4 or Table 5.)

TABLE D. Brightness B_w of a horizontal white diffusing plaque, candles per square foot.

H	B_w (NRL, 1951)	B_w (Kimball, 1916)	H	B_w (NRL, 1951)	B_w (Kimball, 1916)
5°	60.5	---	4°	0.44	1.0
3°	40.0	---	5°	0.14	---
0°	12.7	10.5	6°	0.040	0.13
-1°	7.2	---	7°	0.012	---
-2°	3.27	4.8	8°	0.0040	0.013
-3°	1.27	---	9°	0.0016	---

If the surface of the earth were a uniformly diffuse Lambert surface of diffuse reflectivity R , and if there were no atmosphere between the observer and the surface, the brightness B of the lower hemisphere would be $B = R B_w$. B would be constant for all directions of the lower hemisphere and all altitudes of the observer. For example, for $H = -3^\circ$, $B_w = 1.27$ ca. ft.⁻² (from Table C). Now take $R = 0.06$ and 0.8 which are probable minimum and maximum values. Then $B = 0.076$ and 1.0 ca. ft.⁻², respectively, which are both less than B of the upper hemisphere as seen from B for $H = -3^\circ$ of Table 4. Similarly, for $H = -6^\circ$ and -9° one has the respective minimum and maximum values of H_w 0.0024, 0.032 and 0.0001 and 0.0013 ca. ft.⁻²; these are greater than some of the upper hemisphere values of B for $H = -6^\circ$ and less than others.

If there were an atmosphere between the observer and the surface, B for the lower hemisphere would be between the above maximum and minimum values; but as has been said the exact calculation of the effect of the atmosphere appears complicated and will not be entered upon here.

NIGHT SKY BRIGHTNESS, UPPER HEMISPHERE

Full night occurs when the sun is 18° or more below the horizon. The amount of sunlight, direct or scattered, which remains in the night sky is too small to be of importance here, and the only light which is of concern is the light from the stars and other heavenly apparitions and the light shed down from the upper atmosphere or "air glow". The air glow is on the average five times as intense as the starlight and is of first importance in the following discussion. The air glow is emitted by a luminous shell of atmosphere situated somewhere above 50 km of brightness roughly constant (within a factor of 2) over the earth for all latitudes and seasons and through the sunspot cycle.

TABLE E. Average values of B at night for clear weather, candles per square foot.

P	B	P	B
90°	3.85×10^{-5}	30°	5.18×10^{-5}
80°	3.85	20°	6.22
70°	4.00	15°	6.66
60°	4.00	10°	6.66
50°	4.15	5°	5.92
40°	4.44	2°	1.52

Average values of B of the upper hemisphere observed⁹ from the surface at night in clear weather are listed in Table E for values of P from the zenith to 2° above the horizon; B is the same for all values of Z. B is a minimum at the zenith, increases to a maximum at about P = 15° because at slant angles the observer is looking through increased thickness of the luminous shell and falls below the maximum as the horizon is approached because of attenuation due to haze in the lower part of the atmosphere.

Since the vertical transmission of the atmosphere for diffuse light is greater than 70 per cent in clear weather, the values of B of the upper hemisphere increase to some extent as the observer rises up from the surface. For example, at 50,000 feet B will be greater than the values of Table D by an amount probably less than 30 per cent for the overhead sky, and less than 100 per cent for the sky near the horizon.

Some measurements of the brightness of aurorae and the zodiacal light, and some estimates of brightness of moonlight, are listed in Reference 9. These brightnesses add to the night air glow if such luminous sources are present.

NIGHT SKY BRIGHTNESS, LOWER HEMISPHERE

There are no measurements of B at night for the lower hemisphere. In contrast to the case of twilight this is a simple case and can be worked out theoretically with fair completeness. However, we shall not do this until it seems necessary, but shall merely present a minimum and maximum estimate. It is satisfactory to assume a flat earth, and in this case one has a plane uniformly luminous layer overhead of brightness B_1 extending to infinity; B_1 is the brightness of the zenith sky. The surface of the earth is assumed to be a uniformly diffuse reflecting plane extending to infinity of diffuse reflectivity R. Assume no atmosphere. Then the brightness of the lower hemisphere is $B = RB_1$, and is constant in all directions over the lower hemisphere and for all altitudes of the observer. Maximum and minimum values of R are 0.06 and 0.8. From Table D, $B_1 = 3.85 \times 10^{-5}$, hence, minimum and maximum values of B are 2.3×10^{-6} and 3×10^{-5} ca. ft.⁻². If there is an atmosphere between the observer and the surface B will be between these values, and its exact value will depend upon the haze and clouds in the atmosphere. If the optical properties and distribution of these are specified, B for the lower hemisphere can be calculated for all heights to a satisfactory approximation.

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Discussion:

Dr. Dunham asked if Dr. Hulburt had any measurements within a few degrees of the sun.

Dr. Hulburt reported that there were no such measurements that he knew of.

TABLE 1. Day sky brightness, 10,000 feet, candles per square foot. Theoretical, $\beta = 0.019$.

Z enith P = 90 ^o						
	H	B				
	5 ^o	44				
	10 ^o	56				
	20 ^o	77				
	30 ^o	93				
	40 ^o	109				
	50 ^o	123				
	60 ^o	137				
	70 ^o	146				
	80 ^o	152				
	90 ^o	(157)				
Z = 0 ^o						
	P = 0 ^o	P = 15 ^o	P = 30 ^o	P = 45 ^o	P = 60 ^o	P = 75 ^o
H	B	B	B	B	B	B
5 ^o	(?)	320	172	114	76	54
10 ^o	(?)	(359)	196	130	90	67
20 ^o	1800	(424)	235	156	114	91
30 ^o	1500	450	(259)	177	131	112
40 ^o	1100	449	270	(191)	150	130
50 ^o	1050	431	270	(200)	165	144
60 ^o	950	409	261	201	(175)	154
70 ^o	880	385	248	197	180	(159)
80 ^o	830	355	229	189	173	(160)
90 ^o	820	327	209	175	161	158
Z = 45 ^o						
	P = 0 ^o	P = 15 ^o	P = 30 ^o	P = 45 ^o	P = 60 ^o	P = 75 ^o
H	B	B	B	B	B	B
5 ^o	300	250	142	94	76	48
10 ^o	400	282	160	111	83	62
20 ^o	800	336	188	140	106	87
30 ^o	1020	367	205	161	127	106
40 ^o	980	380	223	177	144	124
50 ^o	930	380	232	187	159	138
60 ^o	880	371	236	190	165	149
70 ^o	850	358	232	188	169	152
80 ^o	830	352	222	182	167	158
90 ^o	820	327	209	175	161	158

TABLE 1. (continued).

 $Z = 90^\circ$

	$P = 0^\circ$	$P = 15^\circ$	$P = 30^\circ$	$P = 45^\circ$	$P = 60^\circ$	$P = 75^\circ$
H	B	B	B	B	B	B
5°	130	194	103	87	64	54
10°	500	211	114	97	72	63
20°	700	240	135	110	87	78
30°	820	266	154	120	102	94
40°	820	285	170	133	117	112
50°	820	302	183	146	131	127
60°	820	313	194	158	143	138
70°	820	319	200	164	150	147
80°	820	323	205	170	157	153
90°	820	327	209	175	161	158

 $Z = 135^\circ$

	$P = 0^\circ$	$P = 15^\circ$	$P = 30^\circ$	$P = 45^\circ$	$P = 60^\circ$	$P = 75^\circ$
H	B	B	B	B	B	B
5°	160	254	112	80	62	51
10°	350	268	124	90	69	59
20°	600	291	144	103	80	72
30°	880	306	156	111	91	87
40°	860	309	163	120	102	100
50°	858	306	168	129	114	114
60°	850	304	172	137	126	129
70°	830	306	180	160	139	140
80°	825	312	194	170	150	150
90°	820	327	209	175	161	158

 $Z = 180^\circ$

	$P = 0^\circ$	$P = 15^\circ$	$P = 30^\circ$	$P = 45^\circ$	$P = 60^\circ$	$P = 75^\circ$
H	B	B	B	B	B	B
5°	190	303	170	104	71	53
10°	380	338	168	110	76	60
20°	600	357	177	116	83	73
30°	800	365	175	116	90	85
40°	870	360	170	120	102	99
50°	880	340	169	124	110	112
60°	862	317	170	131	121	126
70°	848	301	175	142	132	137
80°	830	304	188	167	147	145
90°	820	327	209	175	161	158

TABLE 2. Correction c to be added to B of Table 1 for regions within 40° of the sun for various altitudes of the observer. Candles per square foot.

	10,000	20,000	30,000	40,000	50,000 feet
ϕ	c	c	c	c	c
40°	0	0	0	0	0
30°	16	12	9	6	3
20°	47	38	29	20	10
10°	100	80	60	40	20
5°	(?)	(?)	(?)	(?)	(?)

TABLE 3. U. S. standard atmosphere, and pressure ratios to pressure at 10,000 feet.

Altitude feet	Pressure mm.Hg.	Pressure ratio	Altitude feet	Pressure mm.Hg.	Pressure ratio
0	760.0	1.45	40000	140.7	0.269
2000	706.6	1.35	42000	127.9	.246
4000	656.3	1.25	44000	116.3	.223
6000	609.0	1.16	46000	105.7	.202
8000	564.4	1.08	48000	96.05	.184
10000	522.6	1.000	50000	87.30	.167
12000	483.3	.924	52000	79.34	.152
14000	446.6	.854	54000	72.12	.138
16000	411.8	.788	56000	65.55	.125
18000	379.4	.725	58000	59.58	.114
20000	349.1	.668	60000	54.15	.104
22000	320.8	.614	62000	49.22	.0942
24000	294.4	.564	64000	44.73	.0855
26000	269.8	.517	66000	40.66	.0778
28000	246.9	.473	68000	36.95	.0705
30000	225.6	.432	70000	33.59	.0643
32000	205.8	.394	72000	30.53	.0583
34000	187.4	.354	74000	27.75	.0531
36000	170.4	.326	76000	25.22	.0483
38000	154.9	.296	78000	22.92	.0438
			80000	20.83	.0398

TABLE 4. (Page 1)

Twilight sky brightness, B, in candles per square foot
(Photopic eye photocell) Sacramento Peak, N. M.; Altitude 9200 ft.

P = Altitude of place in the sky, and Z = its bearing from meridian of sun.

H = Altitude of sun.

Z = 0°						
	P = 0°	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
+5°	1000	1000	150	63	35	31
+3°	--	560	97	44	24	21
0°	--	150	37	16.5	9.5	8.0
-3°	20	15	4.7	1.9	1.3	1.0
-6°	0.9	0.7	.18	.06	.033	.022
-9°	.04	.03	.0256	.0218	.0211	.0375
-12°	.0218	.0213	.0333	.0314	.0310	.0476
-15°	.0318	.0310	.0447	.0433	.0425	.0420

Z = 22 1/2°						
	P = 0°	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
+5°	600	500	140	60	35	31
+3°	350	300	94	41	23	21
0°	102	85	34	16	9.5	8
-3°	15	14	4.6	1.9	1.3	1.0
-6°	.68	.67	.17	.06	.033	.022
-9°	.028	.025	.0254	.0218	.0210	.0375
-12°	.0214	.0210	.0330	.0314	.0310	.0476
-15°	.0313	.0498	.0446	.0433	.0425	.0420

Z = 45°						
	P = 0°	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
+5°	200	170	100	50	31	31
+3°	145	140	66	35	23	21
0°	62	50	23	13	9.5	8.0
-3°	9.6	9.7	3.6	1.9	1.2	1.0
-6°	0.4	.35	.10	.046	.031	.022
-9°	.017	.015	.0234	.0218	.021	.0375
-12°	.0376	.0370	.032	.0313	.049	.0476
-15°	.048	.0467	.044	.0432	.0425	.0420

TABLE 4 (Page 2)

 $Z = 90^\circ$

	$P = 0^\circ$	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
$+5^\circ$	130	100	45	35	30	31
$+3^\circ$	90	85	38	28	23	21
0°	37	34	17	11	9.5	8.0
-3°	4.2	4.0	2.2	1.6	1.1	1.0
-6°	.11	.08	.05	.04	.025	.022
-9°	.025	.0246	.022	.0215	.021	.0375
-12°	.0336	.033	.0315	.0495	.048	.0476
-15°	.045	.0445	.0435	.0429	.0425	.0420

 $Z = 135^\circ$

	$P = 0^\circ$	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
$+5^\circ$	160	150	72	47	34	31
$+3^\circ$	100	98	55	35	24	21
0°	32	32	20	13	9.5	8.0
-3°	2.4	2.1	2.1	1.5	1.1	1.0
-6°	.078	.07	.045	.037	.025	.022
-9°	.0236	.0235	.022	.0213	.039	.0375
-12°	.0326	.0323	.0314	.0495	.047	.0476
-15°	.045	.045	.0436	.0428	.0422	.0420

 $Z = 180^\circ$

	$P = 0^\circ$	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
$+5^\circ$	190	170	80	50	35	31
$+3^\circ$	120	115	60	36	24	21
0°	38	37	22	14	9.5	8.0
-3°	2.4	2.0	2.1	1.6	1.1	1.0
-6°	.078	.068	.043	.035	.025	.022
-9°	.0236	.023	.0218	.0212	.039	.0375
-12°	.0328	.033	.0314	.049	.047	.0476
-15°	.0458	.046	.0442	.043	.0423	.0420

Table 5 (Page 1)
Twilight Sky Brightness, B, in candles per sq. ft.
Maryland, altitude 100 ft.

Z = 0°						
	P = 0°	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
+5°	1000	1000	350	150	80	43
+3°	--	600	220	100	62	35
0°	--	150	74	35	21	15
-3°	17	15	9.5	4.0	3.0	2
-6°	0.8	0.7	0.3	0.12	.08	.06
-9°	.035	.03	.0272	.024	.0219	.0215
-12°	.0217	.0215	.036	.0323	.0316	.0312
-15°	.0328	.0321	.0311	.0462	.0457	.044

Z = 22 1/2°						
	P = 0°	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
+5°	450	500	240	120	60	43
+3°	290	300	180	78	50	35
0°	95	90	64	30	20	15
-3°	13.5	13	7.7	3.7	2.5	2
-6°	0.6	0.65	0.3	0.1	.075	.06
-9°	.029	.025	.027	.0233	.0218	.0215
-12°	.0212	.0211	.035	.0322	.0315	.0312
-15°	.0319	.0317	.0311	.0462	.0455	.044

Z = 45°						
	P = 0°	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
+5°	250	260	160	80	50	43
+3°	170	180	130	60	41	35
0°	60	58	50	28	19	15
-3°	9.4	10	5.8	3.4	2.2	2
-6°	.42	.35	.20	.08	.062	.06
-9°	.018	.015	.025	.0228	.0216	.0215
-12°	.038	.0368	.0337	.0319	.0314	.0312
-15°	.0312	.0312	.0498	.046	.045	.044

TABLE 5 (Page 2)

$$Z = 90^{\circ}$$

	$P = 0^{\circ}$	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
$+5^{\circ}$	100	94	80	60	45	43
$+3^{\circ}$	75	80	66	50	34	35
0°	34	34	32	22	17	15
-3°	5.5	6.0	3.5	3	2	2
-6°	.15	.09	.09	.07	.05	.06
-9°	.0254	.0245	.0234	.022	.0214	.0215
-12°	.0335	.0335	.0325	.0316	.0312	.0312
-15°	.047	.047	.0475	.0452	.0446	.0444

$$Z = 135^{\circ}$$

	$P = 0^{\circ}$	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
$+5^{\circ}$	160	150	100	64	48	43
$+3^{\circ}$	110	100	70	50	39	35
0°	39	35	30	20	16	15
-3°	4.0	3.0	3.0	3.0	2	2
-6°	.09	.07	.07	.07	.05	.06
-9°	.0232	.023	.0225	.022	.0213	.0215
-12°	.0325	.0325	.032	.0315	.0310	.0312
-15°	.0456	.0455	.045	.0445	.0443	.0444

$$Z = 180^{\circ}$$

	$P = 0^{\circ}$	10°	30°	50°	70°	90°
H	B	B	B	B	B	B
$+5^{\circ}$	180	170	110	65	50	43
$+3^{\circ}$	120	120	78	54	40	35
0°	42	40	35	23	19	15
-3°	4.0	2	4	3.2	2	2
-6°	.09	.08	.07	.07	.05	.06
-9°	.0232	.023	.0225	.022	.0215	.0215
-12°	.0325	.0325	.032	.0317	.0311	.0312
-15°	.0456	.0454	.045	.0446	.044	.0444

~~RESTRICTED~~

REPORT OF THE WORKING GROUP ON VISIBILITY AT HIGH ALTITUDES

Dr. Duntley reported that the working group on Visibility at High Altitudes had been requested by Capt. Wilbur E. Kellum to evaluate the experimental studies of sky brightness and illumination carried out by Commander Norman Lee Barr of the Naval Medical Research Institute at Bethesda, Maryland. Dr. Duntley read the following opinions and recommendations concerning these experiments which were prepared by the working group:

1. Both random and systematic experimental uncertainties of at least ± 15 per cent and in some instances as much as ± 50 per cent appear to be present in the experimental procedures, but no gross disagreement was discovered when the data were spot-checked against values recently published in the Journal of the Optical Society of America by Packer and Lock.
2. There exists throughout the Department of Defense an urgent need for data of the type Dr. Barr has collected. Many aspects of the defense effort will be aided and accelerated by such data, even at a moderate level of precision and accuracy.
3. The data which have been collected by Dr. Barr should be published without delay for recalculations or recalibrations, in order to provide for utilization and examination by a larger technical audience throughout the Department of Defense. The data should be presented in tabular form similar to that published by Packer and Lock and in other ways if desired.
4. Whether further experimentation is necessary cannot be concluded until the published data are analyzed.

Discussion:

Col. Byrnes expressed the interest of the Air Force in Commander Barr's experimental studies and expressed appreciation to the working group for having evaluated them.

Comdr. Barr questioned the opinion of the working group concerning the magnitude of random and systematic experimental uncertainties in his experimental data.

Dr. Duntley itemized the uncertainties which were evident to the working group. He enumerated uncertainties due to inadequate color correction, uncertainties due to possible misalignments of the telephotometers, and uncertainties due to non-linearity of at least one galvanometer.

The report of the working group on visibility at high altitudes was accepted by the Vision Committee for transmittal to the liaison officers of the military departments.

~~RESTRICTED~~

THE VISIBILITY OF STARS AT TWILIGHT

R. Tousey and M. J. Koomen
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Celestial navigation, as practiced at present, relies during the daytime mainly on the sun. Occasionally use is made of the moon. The noon sun sight gives the latitude. A sight when the sun is near the prime vertical determines the longitude. On shipboard at night it is difficult to use the stars since the horizon cannot be seen well enough; a bubble sextant will not usually give accurate altitudes because of acceleration errors. Aircraft, however, are ordinarily steadier than ships. Therefore, in the air a bubble sextant does give fairly accurate altitudes, and sights on the stars and planets at night are practical.

On shipboard, it is standard practice to sight on the stars during the few minutes of twilight when both the horizon and the brightest stars can be seen, and a fix can thus be obtained.

For aircraft when radio methods are not available, navigation in daytime is by dead reckoning combined with sights of the sun and possibly the moon. At night the stars are used.

The problem of navigation during the arctic twilight, however, is sometimes difficult, when neither landmarks nor the sun can be seen, and the sky is still too bright to permit sighting on the stars. For this reason it was desired by the Strategic Air Command that a study be made of the visibility of stars during twilight.

Star visibility charts and rules are given in the present paper. Although some of the rules are rather approximate, they are sufficiently precise for practical use for two reasons:

(1) Variations in the visibility of stars greater than the errors inherent in the charts and rules are introduced in flight by variable and unpredictable atmospheric conditions, and by the working conditions in the plane. Only very rough corrections for these factors can be made.

(2) Star visibilities change rapidly with the solar depression angle; therefore extreme precision in visibility data is not required. This will be explained further in a later section.

The visibility of stars in the daytime sky was studied by Tousey and Hulburt¹, who presented charts and tables describing the conditions under which it is possible to see stars in full daylight. The computation was made from sky brightness data² for a 10,000 foot altitude and from the point source threshold data of Blackwell³, and of Knoll, Tousey and Hulburt⁴. No data were presented for twilight. The visibility predictions were found in agreement with direct observations of stars through low power telescopes made under controlled conditions. From this work it can be shown that when the sun is at an altitude of over 15° it is impossible for any normal observer near sea level to see any star without an optical aid such as a telescope, or a polarizing filter. Venus, however, can be seen with the naked eye when the atmosphere is very clear provided that the observer knows exactly where to look, and Mars and Jupiter, when at their very brightest might be seen though we are aware of no record.

Weaver⁵ has also computed the visibility of stars in the daytime, twilight, and night skies in a similar fashion, starting from Hecht's⁶ formulas which approximate the point source threshold data, and available data on sky brightness. He was particularly interested in the faintest stars visible to the unaided eye at night, and made no direct observations

during twilight. Only the zenith sky was considered and the attenuation of the atmosphere was neglected.

The twilight case is of particular interest because of the problem of celestial navigation in Arctic regions, where twilight conditions prevail for considerable periods. Charts were desired which would indicate the region of the sky over which stars of a given magnitude could be seen with the unaided eye for solar altitudes ranging from $+5^{\circ}$ to -10° .

The computation of twilight star visibility thresholds was made for the following conditions and data:

(a) The point source threshold data of Blackwell³ were used, multiplied by a factor of two in order to make them apply to an approximate 98% probability of seeing. The values are listed in Table I in the first two columns.

(b) The sky brightness data were those measured by Koomen⁷ et al and given in a preliminary report by Hulburt⁸. The measurements were made from Sacramento Peak, New Mexico, at an altitude of approximately 10,000 feet, and for a very clear sky. Thus they apply to conditions likely to be encountered in flight. Measurements were made over the entire sky for altitudes of the sun from $+5^{\circ}$ to -15° .

(c) The atmospheric attenuation coefficient β was assumed to be 0.017/km, which was the value found to hold for clear air by Tousey and Hulburt². In addition, an attenuation coefficient for ozone of 0.023 was assumed. For 10,000 feet, (5.5 km air at NTP), the total attenuation coefficient was $0.017 \times 5.5 + .023 = 0.117$.

(d) The relation between the scale of stellar magnitudes and the illumination in foot-candles produced by a star was established by taking the magnitude of the sun to be -26.72, (Ref. 9), and accepting 10,000 f.c. as the illumination produced by the sun above the atmosphere. (Actually the latter value is probably too small by 10 or 15%. This amounts to about 0.1 stellar magnitude.)

Under the above conditions the relation between the illumination i produced by a star of magnitude m at an elevation angle θ is

$$i = 10^{-6.688 - 0.4 m} e^{-0.117 \csc \theta} \quad (1)$$

where 6.688 is the constant appropriate to $i = 10^4$ f.c. and $m = -26.72$, and for the exponential attenuation term set equal to zero.

Solving,

$$m = -2.5(\log i + 6.688) - 0.127 \csc \theta \quad (2)$$

Values of threshold magnitude, m_{θ} , for the case of no attenuation, computed from the first term of (2) are given in Table I. The corrections for attenuation from the second term of (2) are given in Table II.

Figure 1 shows a plot of threshold magnitude, in the absence of attenuation, against $\log B$ where B is the sky brightness in c/ft^2 . The corrections for attenuation simply displace the entire curve upward by the correction appropriate to the angle θ . The break in slope at $\log B = -3.6$ is associated with the shift from cone to rod vision.

Figures 2 through 16, present the final charts of star visibilities. Each chart refers to a particular stellar magnitude. The contour lines bound the area of sky above which a star of this magnitude can be seen for the solar depression peculiar to each contour. The

TABLE I

Threshold illumination, i , and stellar magnitude, M_0 , for stars seen against a sky of brightness B and with no attenuation.

$\log B(c/ft^2)$	$\log i (f. c.)$	M_0
2.50	-5.21	-3.70
1.50	-6.07	-1.53
0.50	-6.88	+0.49
-0.50	-7.63	+2.35
-1.50	-8.22	+3.82
-2.50	-8.58	+4.73
-3.50	-8.65	+4.89
-4.50	-9.01	+5.81
-5.50	-9.43	+6.85

TABLE II

Attenuation corrections, $0.127 \csc \theta$: subtract from M_0 to obtain threshold including attenuation.

θ	Correction to M_0
10°	0.73
20°	0.37
30°	0.25
40°	0.20
50°	0.17
60°	0.15
70°	0.13
80°	0.13
90°	0.13

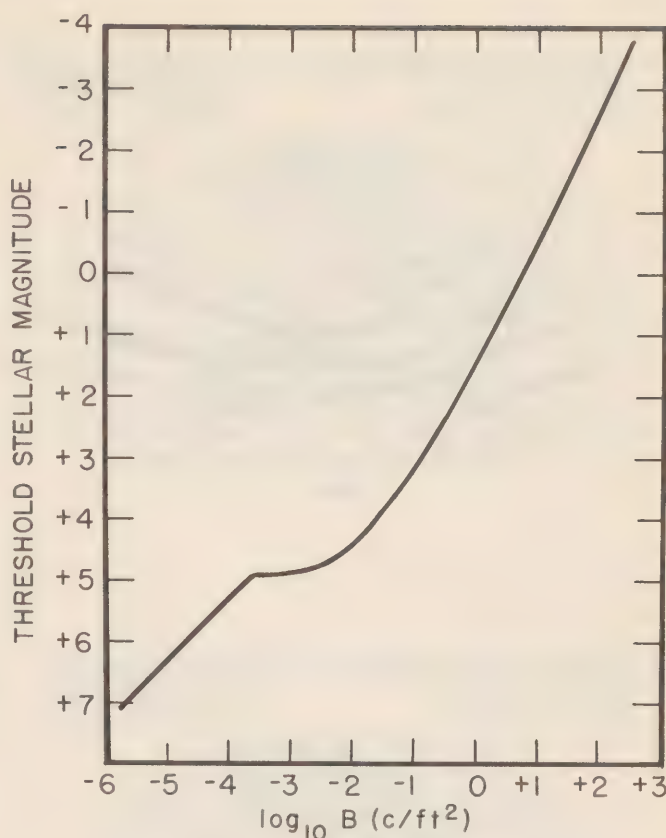


FIG. 1

star can just barely be seen at the contour, and is increasingly easy to see the farther it lies above the contour. Though the data were smoothed, there are probably still some small and unimportant inconsistencies in the charts. The charts were prepared by combining the threshold curve of Figure 1, the attenuation

corrections of Table II, and the sky brightness data of Reference 8.

As an example, at what stage of twilight can Capella, magnitude 0.2, first be seen when at an altitude of 40° and at an azimuth relative to the sun of 75° ? Figure 7, for $m = 0$, is closest, and indicates that the sun must be at least 2° below the horizon.

The star visibility charts can be applied approximately to conditions other than those for which they were computed. This is done by making corrections to the stellar magnitude before consulting the charts. The following are the corrections:

(a) Altitude of observer:

The charts were computed for an altitude of 10,000 feet (9200 feet to be exact). At lower altitudes stars become more difficult to see because the sky is brighter and because the starlight is more attenuated. An approximate correction to sea level can be made by adding -0.1 to the threshold stellar magnitude for each 1,000 feet that the observer is below 10,000 feet. This correction was arrived at in the following fashion:

From Figure 1, the approximate relation between threshold magnitude and sky brightness for the magnitude range $+4$ to -2 of navigational interest is $m = -2 \log B + \text{constant}$.

VISIBILITY OF STAR OF MAGNITUDE -2.5
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

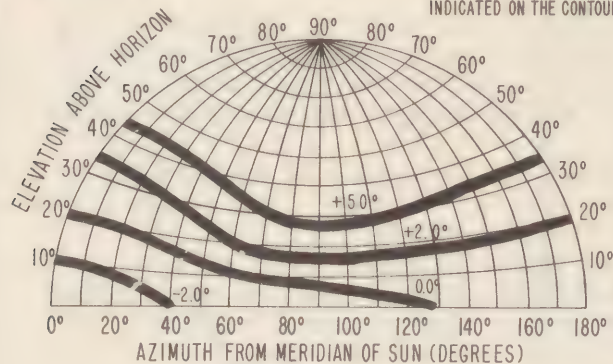


FIG 2

VISIBILITY OF STAR OF MAGNITUDE -2
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

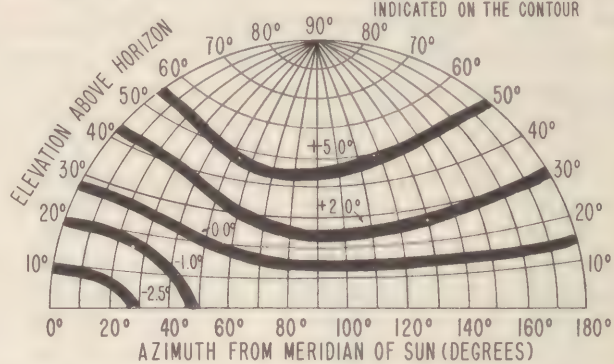


FIG 3

VISIBILITY OF STAR OF MAGNITUDE -1.5
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

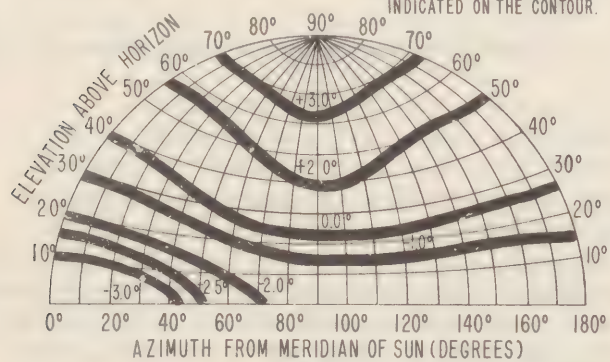


FIG 4

VISIBILITY OF STAR OF MAGNITUDE -1
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

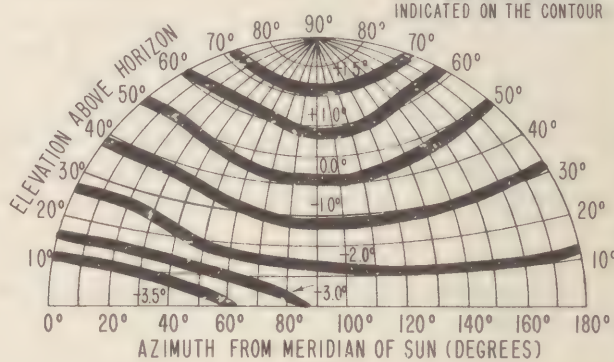


FIG 5

VISIBILITY OF STAR OF MAGNITUDE -0.5
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

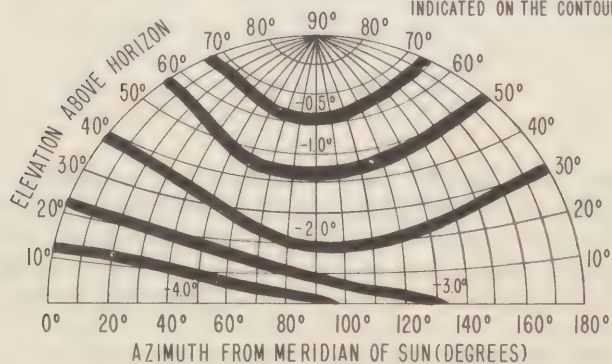


FIG 6

VISIBILITY OF STAR OF MAGNITUDE 0.0
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

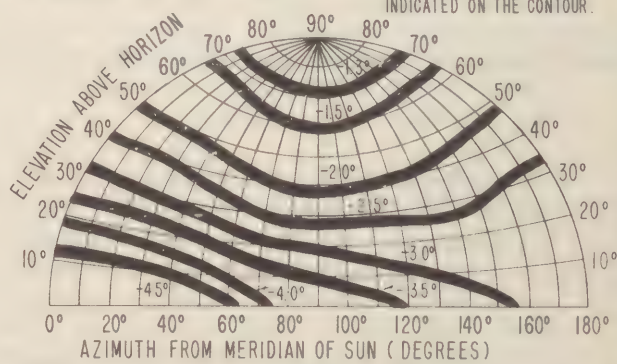


FIG 7

VISIBILITY OF STAR OF MAGNITUDE 0.5
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

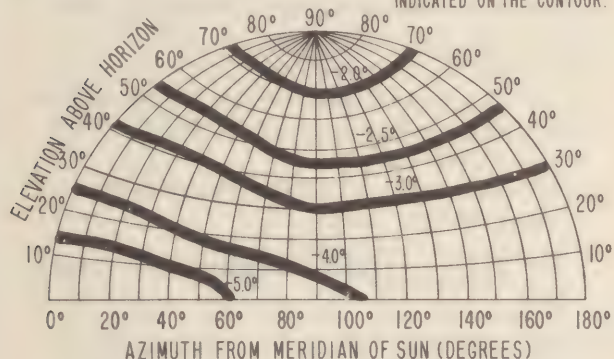


FIG. 8

VISIBILITY OF STAR OF MAGNITUDE 1.0
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

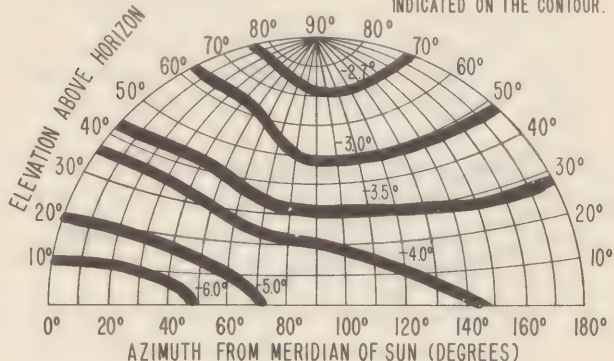


FIG. 9

VISIBILITY OF STAR OF MAGNITUDE 1.5
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

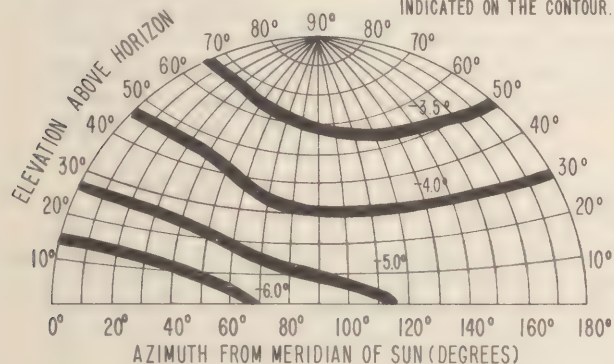


FIG. 10

VISIBILITY OF STAR OF MAGNITUDE 2.0
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

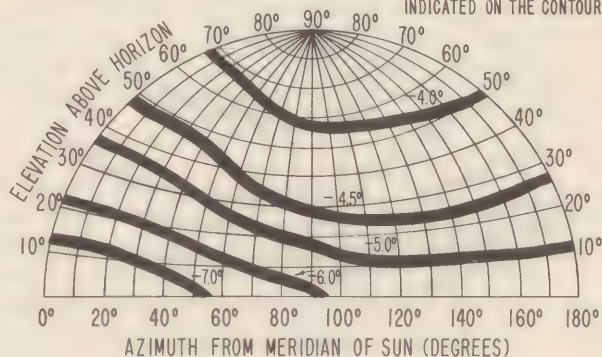


FIG. 11

VISIBILITY OF STAR OF MAGNITUDE 2.5
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

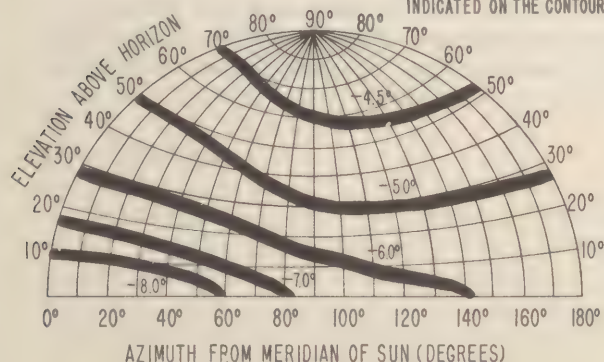


FIG. 12

VISIBILITY OF STAR OF MAGNITUDE 3.0
IN TWILIGHT SKY.

STAR IS VISIBLE IN ANY PART
OF SKY ABOVE CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR

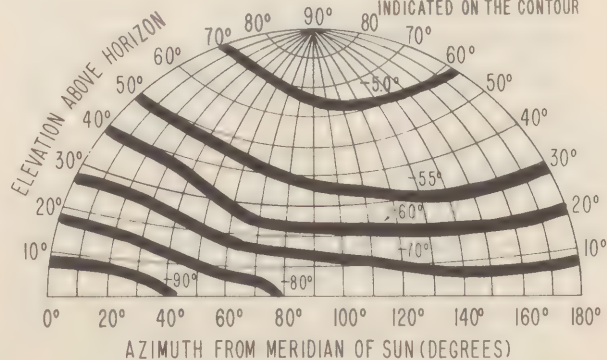


FIG. 13

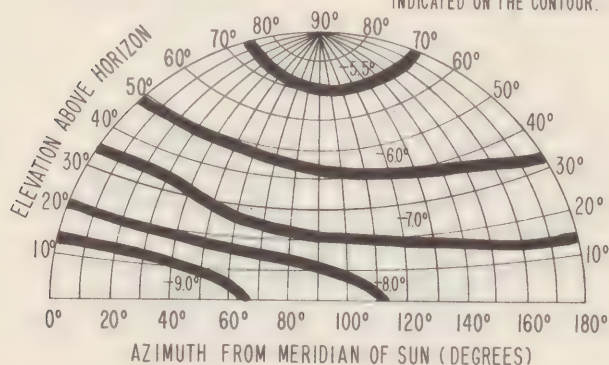
VISIBILITY OF STAR OF MAGNITUDE 3.5
IN TWILIGHT SKYSTAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

FIG. 14

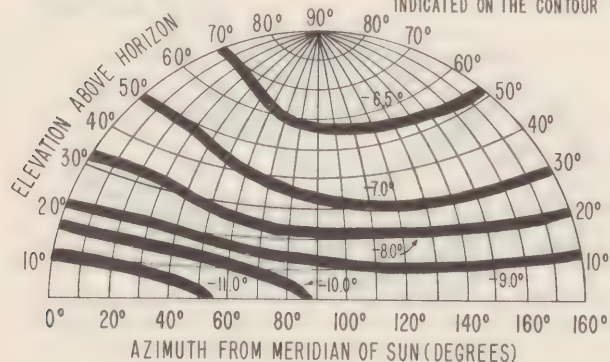
VISIBILITY OF STAR OF MAGNITUDE 4.0
IN TWILIGHT SKY.STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

FIG. 15

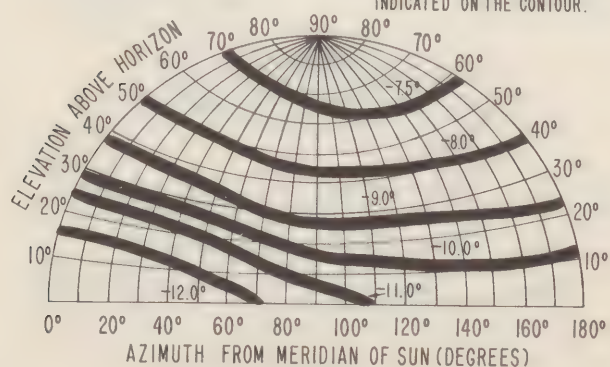
VISIBILITY OF STAR OF MAGNITUDE 4.5
IN TWILIGHT SKY.STAR IS VISIBLE IN ANY PART
OF SKY ABOVE A CONTOUR LINE
WHEN SUN IS AT ALTITUDE
INDICATED ON THE CONTOUR.

FIG. 16

TABLE III

Corrections to be applied to stellar mag-
nitude before using star visibility charts.(a) Altitude:Add 1.0 magnitude for sea level, or
0.1 magnitude for every 1,000 feet be-
low 10,000 feet.Make no correction for altitudes
above 10,000 feet.(b) Field Factor: Add Δm to the mag-
nitude.

Field Factor	Δm	Comments
1	0	Must know close- ly where to look and must search for several sec- onds.
2	0.75	Star difficult to find even if know location.
2.5	1.0	Moderately diffi- cult to find.
5	1.75	Easy to find.
10	2.5	

(c) Telescopes: Add Δm to the magnitude.

Magnification	Δm
1	0
1.5	-0.9
2	-1.5
3	-2.4
4	-3.0

(d) Polarizer: A polarizer will be of
use if the sky near the star is consider-
ably darkened when the polarizer is ro-
tated. In this case add 1 to the star
magnitude. The maximum effect is ap-
proximately at right angles to the sun.

The twilight sky at sea level in Maryland^{7,8} was found to average twice as bright as at Sacramento Peak, New Mexico, over most of the sky above the horizon region. Thus, this brightness ratio corresponds to 0.6 in threshold magnitude. A conservative estimate of the attenuation between sea level and 10,000 feet is 0.4 magnitude. This is based on a 30° altitude of observation, and on the attenuation coefficients of the "Standard Ordinary Clear Atmosphere" proposed by Hulburt⁸. The whole correction to sea level thus becomes 1 magnitude. For intermediate altitudes, arbitrarily interpolate at 0.1 mag. for each 1,000 feet.

For altitudes above 10,000 feet no corrections are given for two reasons:

1. The attenuation corrections are small because the air is clear.
2. The twilight sky is believed to stay at approximately the same brightness as one goes above the 10,000 feet. (cf. Reference 8).

(b) Field Factor:

The ease with which a star can be picked up by the eye depends upon the area of sky over which one can allow his point of regard to move and still be able to see the star. As shown by Tousey and Hulburt¹, for high sky brightness this area is very small when the star is near threshold, and expands to a circle of about 10° diameter when the star is 10 times above threshold. The situation in the twilight range is probably similar, so long as cone vision is used, though an investigation has not been made. As a result, the chance of locating a star is very small if it is near threshold and the observer does not know exactly where in the sky to look for it. If a star is to be of practical use to the navigator, therefore, it must be of greater brightness than the star charts indicate.

An allowance for the practical situation where the navigator must locate a star rather quickly can be made roughly by the use of a "field factor" which represents the factor by which the star must be brighter than for the threshold conditions used in compiling the charts. Table III lists some values of field factor together with comments by Tousey and Hulburt¹. For easy finding, it is probably necessary to have the star 5 to 10 times above threshold, and this can be allowed for approximately by adding 2 to the stellar magnitude before consulting the star charts.

(c) Magnification:

The use of a telescope, of course, makes easier the seeing of a star during twilight, just as it does at night or in the daytime. Bubble sextants are often provided with low power telescopes. The theory of the effect of a telescope on star thresholds was developed by Tousey and Hulburt¹. For low power telescopes the exit pupil is almost certain to be larger than 7 mm and in this case the threshold is inversely proportional to the square of the magnification. Corrections for magnification are listed in Table III. These are to be added to the magnitude of the star one is looking for, and the chart for the resulting magnitude is then consulted.

(d) Polarizer:

A polarizer will aid most in making a star visible, when the star is in the area of sky at 90° to the sun where the skylight is most strongly polarized, and is of little or no use closer than 60° to the sun. A rough rule is that a polarizer will make it possible to see stars that are less bright by 1 to 1.5 magnitude if the sky in the approximate position of the star changes brightness greatly as the polarizer is rotated. In case a polarizer is used it is suggested that -1 be added to the stellar magnitude before consulting the charts.

(e) Moonlight:

The moon, of course, adds to the brightness of the night sky. The sky brightness due to the moon has a distribution like the daytime sky, but is reduced by ratio of the illumination of the moon to that of the sun. This is of the order of 2.5×10^{-6} for the full moon. Therefore the sky brightness due to the moon, when the sky is clear, is of the order of 5×10^{-4} c/ft². This becomes a significant fraction of the sky brightness only when the sun is 10° or 12° below the horizon, that is, when the twilight period is almost past. Therefore, it has no effect on the visibility of stars used for navigation at twilight. The moon may be a hindrance, however, to the visibility of stars close to itself, and particularly so if there is present a thin cirrus.

(f) Ground reflectance:

The sky brightness measurements used in preparing the charts were made over the desert whose average reflectance was of the order of 25 per cent. In the arctic, over ice and snow, the sky brightness will be somewhat greater. No measurements under these conditions are available, but according to the theory of Tousey and Hulburt, the increase will be less than 50 per cent, and will affect star visibilities by less than $1/2$ magnitude. Therefore a correction for ground reflectance is not given.

(g) Refraction:

Unusual refraction conditions are frequently encountered in the arctic. Although there may be an appreciable change in the apparent time of sunset, there can be only a negligible effect on sky brightness, since only the sun's rays that come close to the earth's surface are subject to unusual refraction, and the fraction of the total sky light originating from these rays is small. The solar depression angles in the charts are true and not apparent angles.

Use of Star Charts:

Twilight covers the earth in a belt extending at right angles to the direction of the sun, and completely encircling the earth. The motion of the belt depends on the position on the earth and the declination of the sun. The maximum speed of motion of the twilight belt is at the equator at the equinox, and is about 900 miles per hour. At the other extreme, in the arctic or antarctic at the latitude where the sun just barely sets, or not quite rises, the twilight belt is almost stationary for a considerable period of time. It is here that the problem of navigation may occasionally present difficulties, particularly if the course of the plane is such as to keep it within the twilight belt.

With the aid of the star charts it is possible to make a rough map of the twilight belt, indicating the portions where the various celestial objects can be used for navigation. This map is given in Figure 17, and presents a somewhat over-simplified picture.

The twilight belt is shown running vertically, with the direction of the sun to the left. A scale of nautical miles is given, with 200 mile belts laid off, together with a scale of solar elevation angle. The earth to the left of the sunset (or sunrise) line is in daylight. To the right of the 1,080 mile mark (sun at -18°), there is full night. In between is "twilight" in accordance with the following definitions: Civil twilight is for sun elevation 0° to -6° ; nautical twilight for sun 0° to -12° ; and astronomical twilight for sun 0° to -18° .

There are shown on the map the portions of the twilight belt where practical navigational use of the various celestial objects can be made. The criterion for usefulness was that the object should be visible over most of the sky, (above 10° opposite the sun, above 20° at right angles, and above 30° to 40° toward the sun), using the unaided eye, and

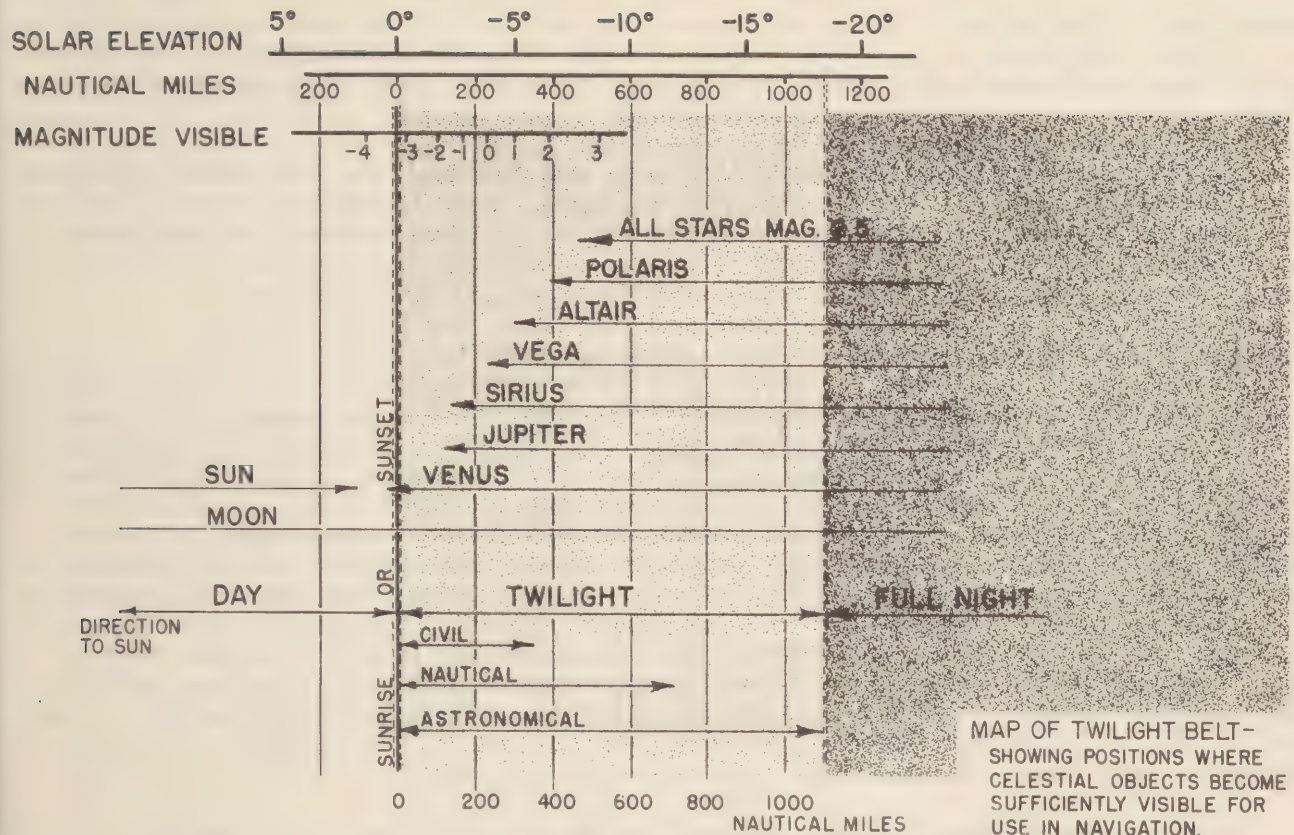


FIG. 17

allowing a field factor of 2.5, (one magnitude), in order to make sighting only moderately difficult. The map applies, of course, to a 10,000 foot altitude and a clear sky. The scale of magnitudes shows the visibility limit, and the arrows indicate the limits for certain selected objects.

The sun is of use from daytime toward sunset until the uncertainty in refraction correction becomes intolerable. We have arbitrarily set the useful altitude limit at 2° or 120 miles. The moon is visible throughout twilight, and is the only object that may be seen with ease through this period.

Venus is a very good object for navigation and can be seen satisfactorily starting at about sunset. Moreover, it is possible to use Venus throughout the day if it is well situated and if time is available to locate it. This is also true for sea level if the sky is extremely clear.

Jupiter and Sirius can be employed if the observer is at least 150 miles into the twilight. For the 9 stars of magnitude between 0 and 1 a distance of 250 to 300 miles is required, while all stars of magnitude under 2.5 can be seen beyond 500 miles.

Thus, it becomes apparent that aerial celestial navigation is difficult mainly within a band of about 300 miles width extending between solar altitudes $+2^{\circ}$ and -3° , and within which objects other than the moon are not easy to see. In an airplane, ordinarily, the 300 mile twilight belt passes rapidly. In the Arctic however, the plane's course may be such

as to carry it largely inside the belt where navigation is difficult. In case the pilot finds himself lost in this region he should remember that an hour's flying time, or less, away from the sun will carry him to a place when celestial navigation is possible. In the event that a flight must be made within the twilight belt, the charts make it possible to discover in advance which stars and planets can be sighted.

By using a low power telescope, and possibly a polarizing filter, and preparing beforehand altitude versus time curves for the celestial objects to be located, it should be possible to narrow the belt over which navigation is difficult, though it is doubtful if objects other than Venus, Jupiter, and possibly Sirius, Mars and Canopus can be used with the sun showing over the horizon.

Test of Charts:

Observations were made from a point in Maryland close to Washington, D. C., and near sea level on 11 January 1952 at sunset. The sky appeared to be very clear until just after sunset, when thin clouds extending from the western horizon up to about 60° became visible. Four stars, Capella, Aldebaran, Vega and Polaris, were chosen and an attempt was made to locate them at the earliest possible moment. The sun was setting at a rate of 1° in six minutes, and the sky was becoming darker by some 20 per cent per minute; therefore, observing conditions were moderately favorable for determining precise thresholds.

The procedure used was to locate the star first by means of an 8 x 60 binocular before it was visible to the naked eye. Then, the binocular was used as a sighting device, using one side and one eye, and searching simultaneously with the other eye unaided. This was not easy to do but did result in establishing the moment of first visibility for Capella and Polaris to within a minute or so.

Rough estimates were also made of the angle in the visual field through which the stars could be seen as twilight progressed. It appeared that when the star was visible over a circle of 5° radius it was easy to see, while for a 2° radius it was moderately difficult.

TABLE IV

Star Visibility Observations
Washington, D. C., January 11, 1952

Celestial Object		Time	Solar Altitude	Visibility	M_t	$M_t - (M+1)$
Capella	M = 0.2	5:23 PM	-3.8°	Vy. diff.	1.5	0.3
	H = 40°	5:28	-4.7°	to 3°	2.5	1.3
	Z - $Z_{\text{sun}} = 171^\circ$	5:34	-5.7°	Easy	3.4	2.2
Aldebaran	M = 1.1	5:26 PM	-4.4°	to 1°	2.1	0.0
	H = 35°	5:29	-4.8°	to 2°	2.5	0.4
	Z - $Z_{\text{sun}} = 150^\circ$	5:34	-5.7°	Easy	3.1	1.0
Polaris	M = 2.1	5:36 PM	-6.1°	Vy. diff.	3.5	0.4
	H = 39°	5:40	-6.9°	to 1.5°	4.1	1.0
	Z - $Z_{\text{sun}} = 113^\circ$					
Vega	M = 0.1	5:29 PM	-4.9°	to 2°	1.5	0.4
	H = 22°	5:36	-6.2°	Easy	2.6	1.5
	Z - $Z_{\text{sun}} = 57^\circ$					

In Table IV are given the results of the experimental test of the charts. The magnitude and position of the star relative to the sun are listed. The first column is the solar altitude when the observation was made, and the second refers to the difficulty of the observation. The threshold magnitude, M_t , was derived from the star charts for each observation and is given in the third column. Finally, in the last column the threshold magnitude is compared with the true magnitude of the star in order to determine whether or not the difference is in accordance with the corrections given in Table III; from M_t unity is subtracted to refer the charts to sea level; the remainder, given in column four, represents the correction for field factor.

All four stars were first sighted as predicted by the charts to within 0.4 magnitude. This was considered good agreement for measurements of this sort, where the atmosphere in the west was not completely clear, and when a threshold observation had to be made within about a minute of time and no second try was possible. It is not clear why Aldebaran appeared to be relatively easier to see than Capella, but it may have been due to its color, which is orange; this contrasted more with the still-visible blue of the sky than did the yellow of Capella.

Easy sighting conditions were noted for three of the stars corresponding to field factor values from 1.0 to 2.2 magnitudes. This was so much a matter of judgement that the lack of perfect agreement with the field factor comments of Table III is not surprising, though Aldebaran, again, seemed unexpectedly easy to see.

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7. M. J. Koomen, C. Lock, D. M. Packer, R. Scolnik, and E. O. Hulburt, Jn. Opt. Soc. Am., 41, 876, 1951.
8. E. O. Hulburt, "Measurements and Estimates of Sky Brightness for All Altitudes of the Sun for Various Altitudes of the Observer above the Surface of the Earth, Naval Research Laboratory, December 1951.
9. H. N. Russell, R. S. Dugan, and J. Q. Stewart, "Astronomy", Ginn & Co., Boston, Mass., 1945, Table IV.

Discussion:

Col. Byrnes expressed his gratitude to Dr. Tousey for preparing the paper on the visibility of stars. Col. Byrnes commented that the information should prove very useful to the Air Force in connection with navigation in the Arctic regions.

Mr. Middleton stated that he thought Dr. Tousey should be congratulated for the clear way in which he presented his results in the two charts.

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- Group Capt. McCulloch asked whether the fact that the earth flattens at the poles would change the area of a twilight zone to an appreciable extent.
- Dr. Tousey stated that he did not think the change would be significant.
- Dr. Dimmick questioned Dr. Tousey's remark that it is not possible to see stars in the periphery when they can be seen in the fovea.
- Dr. Tousey commented that this result was obtained only when the background luminance was high.
- Dr. Blackwell reported that he is collecting data on the luminance difference threshold for point sources at various locations in the visual field. At high luminance, the threshold is approximately 100 times as great 12° from the fovea as in the fovea itself. Similar measurements at twilight luminance levels are being made. It is expected that there may be considerable change in the sensitivity map at the lower luminance level due to the different proportions of rods and cones which will be operative at the different luminance levels.
- Mr. Douglas commented that stars are difficult to see near threshold and that most subjects will give up easily. There are cues which can be used, however, if one trains oneself to use them.
- Dr. Dunham suggested that it might be possible to enhance the visibility of certain stars by using color filters. For example, some stars are sufficiently red so that a red filter might produce appreciable enhancement.
- Dr. Tousey commented that the difficulty with using filters is that it dims the background luminance and hence increases the threshold.

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Proposed Field Tests of the Tiffany Visibility
Forecasting Nomographs

Rolland H. Waters
Dunlap & Associates, Inc.

The privilege of appearing before this Committee comes about as a result of some earlier correspondence and a long-distance conversation with Mr. Blackwell. I want to thank him for his invitation to be here, and I hope that the problem to be discussed will be of sufficient interest to justify your listening to it.

For the past year and a half, my group has been working on a series of studies assigned to us by the Office of Naval Research with the collaborative interest of the Navy Hydrographic Office and the Aeronautical Chart and Information Service, among others. The general area of our investigations was described as "the study, development and improvement of graphic aids to air navigation". The term "graphic aids" was given a broad definition and made to include all printed materials, such as charts, books, pamphlets, tables that contained matter of interest to the navigator of the aircraft. Top priority was given to the study of charts for high-speed, high-altitude, single-operator aircraft. Studies on this particular project have been completed on such problems as the production specifications for a chart of increased legibility in the sense of more rapid comprehension of details presented; the selection of the natural and cultural objects to be represented on the chart; substitutes for charts and other related topics. The outcomes of these studies are contained in a series of reports already issued. Current studies are being directed toward the determination of better symbols for presenting chart information, the legibility of different charts under day and simulated night flying conditions and a systematic study of the different types or kinds of charts required to satisfy naval air requirements. The scope of possible studies is such as to justify our interest in a great variety of specific problems. Among these problems that of the visibility of objects from different altitudes is the one to be presented this morning. The preceding digression has been made so that this specific problem can be evaluated against its appropriate background of related information.

The remainder of this paper will be devoted to a presentation of the problem of object visibility from altitude as it is being met in present-day aeronautical operations, a summary of work accomplished by us on this problem to date and some suggestions concerning the requirements to be met by additional data.

Aeronautical charts are designed as instruments by means of which the navigational needs of any given aircraft mission may be met. They are devices which provide the navigator with the information necessary to fix his position while in flight. The specific requirements of such charts vary with the introduction of new aircraft and the emergence of new types of missions. The requirements include such things as chart size, chart scale, amount of terrestrial detail presented, rapid reading and ease of comprehension. Aircraft that fly at great speeds and altitudes present needs that differ from those that fly at slower speeds and lower altitudes. The military operations taking place in the Korean theater are demonstrating the critical necessity of charts that make the identification of specific targets sure and accurate. In this area navigation must be accomplished by pilotage; radio aids are absent. This same accuracy is required, although it is not so critical, for cross-country flights over friendly territory in which radio aids are available. Nevertheless, in the event of radio failure, the pilot is forced to rely upon his visual identification of terrestrial features to fix his position and pilot his aircraft.

The problem of the selection of terrestrial features to be shown on the chart is thus one of primary importance. Objects must be selected that can be seen, discriminated and identified. To avoid cluttering the chart with so much information as to make it illegible,

the number of objects to be selected should be the minimum required for safe and efficient navigation. It is this problem of object selection to which attention is directed.

In an earlier report, it has been pointed out that the selection of the objects to be symbolized on aeronautical charts may be based on (1) the reports of features found useful by pilots and other qualified personnel and (2) technical criteria of visibility based on the size of the object, its contrast with the background and the effect of atmospheric conditions. These latter criteria or principles of selection are drawn from the fields of psychology, mathematics and meteorology.

The accumulation of the necessary information from the reports of pilots and others is a slow process. Such information would be limited to those areas actually flown over; it would not be applicable to uncharted areas; unless missions were flown for the purpose of making systematic surveys or observations, the information would be scrappy or spotty and incomplete. It would seem that other techniques would be necessary if complete coverage of all areas is to be achieved. The reports by pilots will still be utilized to supplement and correct the charts as they appear.

Photographic surveys should provide a rich source of information from which the cartographer may make his selection of features. He will need to rely upon psychological principles, mathematical and meteorological data as guides in this selection process. The psychological principles of most use will be those drawn from the field of perception. They will embody those conditions which made for ease of discrimination and identification of objects -- their size, contrast and shape, form or gestaltian characteristics. In the application and utilization of these principles, the cartographer will need help from the field of mathematics and meteorology. These fields will assist him by supplying the information necessary to select objects large enough to be seen and that have the contrast necessary to withstand the attenuation of this contrast introduced by the atmosphere.

These different criteria are given a somewhat elaborate treatment in an earlier report but a brief summary here is required. In that report object size is treated in terms of the size the object must be to subtend an angle of one minute of arc at the eye. This unit was selected because of its agreement with the standards set for normal visual acuity. Furthermore, the pilot is not interested in objects lying at the threshold; at least he is not interested in having all such objects presented on the chart. To do so would result in a chart so densely populated with information as to be worthless. In terms of this unit, then, tables and graphs were prepared showing the minimal dimension and minimal area required when the observer is at different altitudes and looks along different lines of sight toward the ground. These mathematical relationships of course neglect all but the geometry involved. They were developed without reference to questions of contrast, illumination and atmospheric attenuation.

For the purpose of taking these latter conditions into account, use was made, in our earlier report, of the nomographic visibility charts prepared by Duntley. I assume most of you are acquainted with these charts. They are beautiful. They are based on the extensive threshold data obtained by Blackwell at the Tiffany Foundation and mathematical and meteorological results from studies of the scattering effects of the atmosphere, all set forth in graphs from which the variables can be picked off.

Now the practical navigator and cartographer are primarily interested in the empirical validity of such theoretical charts and graphs as I have been describing. The charts and graphs are accepted as beautiful examples of the mental and intellectual powers of the theoretician but the significant question for the man in the plane is "Will they work? Do they actually provide information that is of practical value?" As applied scientists, we cannot, it seems to me, be disdainful of this attitude. Consequently it was recommended at the conclusion of the study that empirical checks of the nomograph visibility charts be run. It is in connection with such possible checks that the following suggestions are made.

(Incidentally, it may be asked whether the nomographs which were, as I understand it, prepared for a somewhat different purpose are really necessary for the particular purpose under consideration, the selection of terrestrial objects for presentation on aeronautical charts. It may be that the charts presenting the simple geometrical size relationship are adequate.)

The nomographic visibility charts, or the visibility forecasting nomographs, to use the words of the title, show the predicted visibility of objects as determined by the interrelations among the following variables:

1. The size of the object being observed
2. The contrast ratio between the object and its background
3. The general level of illumination
4. The sky-ground ratio
5. The altitude from which the ground object is observed
6. The angle the observer's line of sight makes with the horizontal
7. The meteorological range
8. The presence of "standard" atmospheric conditions which have been assumed in the development of the basic underlying formulas.

The problem of developing a technique for the empirical validation of the predictions made from this chart has been the subject of some discussion between myself, Mr. Duntley and Mr. Blackwell. This discussion is directly responsible for Mr. Blackwell's suggestion that I bring the problem before you.

The general procedure would seem to involve the selection of some target objects for observation; the determination by suitable means of the illumination and atmospheric variables in the list above; an observer reporting on the visibility of the target objects from different altitudes and horizontal distances from the objects; a system of communication between this observer and those on the ground; and the determination of the position of the aerial observer relative to the targets so that the angle of his line of sight could be determined. This procedure might be spelled out in more detail as follows:

1. The atmospheric and illumination variables should be obtained by instrumental means. These instruments would give the level of illumination, the sky-ground ratio, the meteorological range and the contrast ratio between the target objects and their background.
2. The target objects might be a number of circular areas forming a series from light to dark gray. These would not have to be very large; a diameter of ten feet would suffice. These should be laid out with reference to some visible landmark so that the problem of searching the area for them would be avoided. Such a series would provide for the accumulation of several judgments by the aerial observer on each approach or departure from the experimental area.
3. The aerial observer(s) might be sent aloft in a captive balloon, a helicopter or a slow flying aircraft. The use of the last would permit several "passes" at the same or different altitudes. Some form of communication with the ground would have to be provided so that the observer's reports could be correlated with his position relative to the target. He (or they) would report the disappearance or appearance of the target objects.

4. The determination of the observer's position relative to the target might be obtained by getting the angle of elevation from the ground together with the aerial observer's report of his altitude or by means of radar tracking equipment.

In the experimental design, the dependent variable might be taken as the angle of the line of sight at which the objects become visible or invisible. This angle determines the value of the optical slant range or R values shown on the nomographic visibility chart. Statistical comparisons would be made between the theoretical and empirical values.

Suitable arrangement might also be made by which the contrast between object and background could be measured photometrically. Such arrangements would make possible the taking of successive photographs of the target object and its background at different altitudes. These could then be subjected to the type of analysis being made currently in Duntley's laboratory and the results correlated with the empirical observations.

So much for an outline of the proposed field tests. What would be the outcome? Agreement between empirical observation and theoretical prediction would simply mean that the nomograph does provide the basis for the confident prediction of object visibility. Everybody would be happy, the theoretician has been justified, practical needs have been met.

Disagreement between theory and observation would be something else. Such a finding would be difficult to interpret. Certainly it would not prove that the nomographic charts are mathematically incorrect. The lack of agreement might mean that the "standard atmosphere" assumed by the nomographs was not present on the day of the tests. If this were true, the need for determination of the divergence of such atmosphere as encountered from the "standard" would exist. Again the discrepancy between theory and observation might be found constant. This would permit the application of a correction factor to the nomographs and thus make possible their immediate practical use.

Whether the procedure here outlined is adequate or whether some other must be designed, the desirability of establishing the practical validity of the nomographic visibility forecasters remains.

Discussion:

Dr. Blackwell stated that he felt obligated to comment on Dr. Waters proposed research, having suffered through the ordeal of field tests between 1947-1949. The Roscommon field tests proved that if you can go into the field and use a laboratory psychophysical method, you get a laboratory answer. In applying the Tiffany nomographs to a practical problem, one of the principle problems is to evaluate the extent to which the visual task involved in the field differs from the visual task required of subjects in the laboratory experiments upon which the monographs are based. In the laboratory experiments, the targets were uniformly bright and of simple geometric shapes. The subjects knew where to look and were forced to choose the most likely location in which the target might appear. The visual task in visual reconnaissance from aircraft is obviously very different from this task.

Dr. Blackwell continued by stating that he believed the most important thing Dr. Waters should do is to determine the extent to which the visual task required in visual reconnaissance from aircraft differs from the task required in the Tiffany laboratory experiments. This might be done by studying visual thresholds under simulated conditions of visual reconnaissance. Another good way to simulate would be to take photographs from an aircraft and use the photographs for a study of thresholds in a laboratory. This principle of testing "field factors" with films of field conditions is one which seems to have very general utility. Having gotten some idea of the difference in threshold

between a simplified visual task such as that required in the Tiffany laboratory experiments, and the visual task involved in reconnaissance, Dr. Waters could then attempt to utilize the Tiffany nomographs with an appropriate correction factor. The nomographs cover wide ranges of conditions. One would suppose that the conversion factor would be comparatively constant over this wide range of conditions. Obviously if the conversion factor depended upon the particular conditions of physical variables, there would be no advantage in trying to use the Tiffany nomographs.

Dr. Blackwell continued by stating that there was a second major uncertainty in Dr. Waters' attempted application of the Tiffany nomographs. This concerns the extent to which one can predict contrast reduction along slant paths. Dr. Blackwell concluded by stating that in his opinion Dr. Waters would get very poor checks of the Tiffany nomographs if he continued with the experimental program as planned. The question is, what would the poor checks prove? They would not prove that the nomographs are wrong. They would prove that the application of the nomographs was made in error.

Dr. Blackwell expressed his hope that Dr. Waters would attempt to study the problem of visual reconnaissance step by step so that the problem could be understood. This course of action should be followed rather than merely attempting to predict visual ranges from the Tiffany nomographs and ascertaining to what extent the ones obtained in field experiments are different.

Dr. Duntley stated that he would like to second what Dr. Blackwell had said. Dr. Duntley emphasized the difficulties of attempting to predict contrast reduction along slant paths. Dr. Duntley stated that he believes our experience has shown that the nomographs can be used, provided one has all the information necessary to make the proper application. The time is premature to do the combined experiment which Dr. Waters suggests without study of the variables which are undoubtedly present.

Mr. Middleton commented that the nomographic charts which Dr. Duntley prepared for Dr. Waters appear to be quite suitable for use with the slant range problem. The important thing is, however, that it is not possible yet to measure the quantities which must be used in constructing and applying the nomographic charts.

Lt. Comdr. Farnsworth expressed his concern with the basic assumption that the eye can resolve a one minute of arc test object. It would seem that Dr. Waters seems to assume that the eye can resolve a one minute of arc test object regardless of its character. It is of course well known that entirely different acuity thresholds are obtained with different kinds of test objects.

Mr. Corwin reported that the Bureau of Aeronautics is preparing equipment for measuring contrast reduction along slant ranges. This equipment is expected to be ready during the next year.

Dr. Tousey commented that he was not sure the slant range equipment would be ready that soon.

Dr. Waters stated that he had felt reluctant about presenting this paper before the Vision Committee, and that he now believed the proposed program of research would be delayed indefinitely.

SUMMARY OF THE REPORT OF THE
COMMITTEE ON HIGHWAY SAFETY RESEARCH

Dr. Blackwell reported on the formation of the Committee on Highway Safety Research within the structure of the National Research Council. The committee is a policy and steering committee whose members represent various appropriate committees of the National Research Council. Dr. Blackwell reported that he had been asked to serve on the committee representing the Vision Committee. The NRC committee on Highway Safety Research has as its function stimulating safety on the highways in a variety of ways. The Executive Secretary of the Committee on Highway Safety Research is Dr. T. W. Forbes. Dr. Forbes has summarized the status of research in highway safety as one means of coordinating research in this field. The Committee is planning a coordination conference for this summer to bring together technical people from the various scientific disciplines related to highway safety and traffic with highway specialists.

INVESTIGATION OF LOW CEILING-LOW VISIBILITY CONDITIONS AFFECTING SAFETY OF AIRCRAFT LANDINGS

I. Objectives

Weather conditions are vital factors in the problems of increasing the safety of landing and take-off operations of aircraft, of minimizing the relative frequency of missed approaches, and of maximizing the acceptance rates of airports. In harmony with this fact, from the beginning of aviation weather service the Weather Bureau has maintained as among its foremost objectives the development of equipment to measure accurately the meteorological variables important to aircraft landing operations, and the development of methods for short-range forecasting of these variables. Such forecasting will be necessary in the long run to bridge the gap in time between the instant the meteorological observation is made and the instant the aircraft is subjected to the conditions as they may occur, allowing time for reduction of data, communications to pilot, etc. The attainment of these objectives has become more critical and difficult with the evolution of modern types of high-powered aircraft and of modern types of landing aids, permitting operations under more adverse weather conditions. The necessity of keeping pace with these advances has been aided by the development of electronic techniques which have been utilized in striving towards the objectives.

II. Present Status, and Recent Developments

Up to the present, horizontal visibility at the surface and ceiling height have been considered the weather elements of primary importance for regulating airport traffic. Generally, visibility is based on observations of objects or lights by eye, and ceiling on observations of amount of cloud by eye and measurements of cloud base height by ceiling balloon, ceiling light, or ceilometer. The present-day ceilometer provides two readings every twelve minutes.

As a step in the program, the Weather Bureau has developed a new type called the "rotating beam ceilometer" which now yields a reading every 24 seconds and new developments are underway to increase the rate. The National Bureau of Standards has also developed an apparatus called a "transmissometer" for giving substantially a continuous record of the transmissivity of the horizontal path (now 750 feet long) which is sampled. From the latter, a corresponding visibility may be determined under certain assumptions. Both the rotating beam ceilometer and the transmissometer are being tested at Washington National Airport. These two devices require calibration experiments to relate their indications to visual observations made by a pilot or observer under the same conditions. Such experiments are underway or are planned to be carried out in the very near future.

III. Natural Limitations on Measuring Apparatus

The problem of securing ceiling and visibility data is complicated by the fact that the devices used for making the measurements cannot exactly duplicate (1) the characteristics of the human eye; (2) the variable conditions of brightness and illumination that govern its performance; (3) the effect of the motion of the aircraft relative to fixed objects on the pilot's ability to detect or recognize them; and (4) the qualities of the different objects or lights whose visual range - horizontal, slant, or vertical - is desired. Moreover, the devices cannot be located where they would yield most representative results; namely, in such locations in space that they may "see" the atmosphere and earth from the point of view of the pilot instantaneously at successive positions of the aircraft during an approach and landing operation. The bearing of these considerations on the subject is better seen upon scrutinizing the matter more deeply, as is done in the next section.

IV. Analysis of the Problem

Certain aids have been provided to pilots for purposes of assisting them to locate and orient their aircraft with respect to the runways of major airports at which landing is sought, and to assist in guiding the aircraft to a safe landing. Among the aids that may be mentioned are high-intensity approach light and runway light systems, ILS and GCA approach systems, and Automatic Approach Couplers. Despite these aids low ceiling and/or visibility conditions remain as factors seriously affecting the landings because, psychologically the pilots deem it essential that they be able to see the ground or the lights toward the final approach through whatever cloud, dust, fog, haze or precipitation may obscure the surface. Even with the Coupler pilots feel it necessary under these conditions to be able for purposes of safe guidance (a) to establish visual reference to the ground in order to locate themselves prior to committing the aircraft to a landing, (b) to establish and maintain visual reference, first, with respect to an adequate minimum extent of the approach light system and, second, with respect to an adequate minimum extent of the runway or its light system, depending on the brightness of the background and the illumination conditions.

In the early stages of the approach under low ceiling/visibility conditions, the pilots have the problem of searching a spatial region visible through the windshield or side windows of the aircraft in order to detect and recognize, first, landmarks in the neighborhood of the airport and, second, the approach and runway light systems of the airport. This problem is especially aggravated when the aircraft is not equipped with an Automatic Approach Coupler because the spatial region to be searched is so much the greater without its aid in following the glide path. Searching under adverse conditions takes time and this is at a premium, especially with high-speed transport. Often the conditions involve precipitation which reduces visibility through the windshield when precipitation is heavy or rain repellants are not used. Fogging within the windshield during rapid descent under low-temperature conditions not infrequently reduces visibility from the cockpit. The finding of the approach light system by a visual search on the part of the pilot depends to a great extent on (a) the solid angle or cone available for seeing the ground from the standpoint of the pilot or co-pilot in the cockpit (that is, the spatial region about the aircraft not excluded from view by the cockpit cut-off: the fuselage, engines, instruments, and framework which are in line of sight of the pilots), (b) the transmissivities of the atmosphere in the directions available to view, (c) the candle power intensity distribution and the design of the approach light system, (d) the background brightness against which the lights must be seen, and (e) the threshold of illumination and the minimum visual cues required by the pilots for detection and recognition of the system. Similar factors govern the detection and recognition of the runway light system.

The problem of seeing the runway per se involves additional factors such as (f) the apparent brightness contrast of the runway with respect to its immediate surroundings from the point of view of the pilot.

Prior to the aircraft approach, the slant visual range is to be derived on the ground by a computation dependent upon items (b), (c), (d), and (e) or (f).

In respect to those factors of the problem which relate directly to the pilot, much depends on his experience, judgment, training and familiarity with the particular airport, its facilities and the environs. The condition of his eyes and the level of brightness to which they are adapted are also of vital importance.

During the course of the flight down the glide path, the pilot must make a decision before a critical altitude is reached whether to continue on in to a landing or to make a missed approach. Going below such a critical altitude,* depending on the aircraft, is

*Critical altitude is defined as the minimum height above airport level to which an approach to landing can safely be continued without visual reference to the ground.

tantamount to committing the aircraft to a landing. If the navigation aids such as ILS, GCA and Automatic Approach Coupler permit the pilot to go safely below the critical altitude along the glide path without his establishing visual reference to the ground, it is necessary to be able to assure the pilot that he will be able, first, to see the approach lights and the runway lights while airborne in time to align his aircraft and make a flare-out for a safe touchdown near the threshold of the runway, taking wind and turbulence into account, and, second, to see enough of the runway lights and/or texture of the runway to maintain a run safely within the confines of the runway after touchdown is made. Usually visibility of at least about five (5) runway lights at 100-foot intervals on both sides of the runway are considered to be necessary at night or under gloomy, low visibility conditions in daytime to permit safe execution of the landing and run operations. One may readily conceive of the importance of satisfying criteria such as those just described by contemplating the effect of a layer of dense ground fog through which lights are visible at altitudes above the fog but are not visible within the fog.

It will be evident from the foregoing that the problem involves (1) the aircraft and its cockpit cut-off; (2) the atmospheric transmissivities in various directions on the course; (3) the candlepower and design of the lights; (4) the terrain and the background brightness; (5) the pilot in respect to the illumination thresholds and visual cues for detection and recognition under various conditions of adaptation of his eyes to the prevailing brightness, his experience, etc.; (6) the apparent brightness contrast of runway versus its environment and the contrast of texture on the runway; (7) the rapid evaluation of data and preparation of forecasts to indicate whether or not the approach and landing operations may be safely executed at the times the operations will be attempted; (8) the rapid appraisal of the situation yielding sound air traffic control decisions; and (9) the rapid communication of the pertinent airport traffic control directives, forecasts and other meteorological information, etc., to the pilots concerned, and the presentation and display of the information in most comprehensible and useful form.

A review of these factors discloses that many of them are variable, as for example owing to movement and formation of clouds or fog; development of fog in patches of different density; space-time changes in height of cloud bases and of associated precipitation; changes in the position, structure, density and thickness of cloud masses and precipitation interposed between sun and pilot, between sun and airport, and between pilot and surface. The adaptation of the pilot's eyes to the prevailing brightness level varies as he progresses from bright to darker conditions, or vice versa. To a certain extent, the tension of the pilot under the responsibilities of safely bringing his aircraft to a landing and his attentiveness, experience, ability and skill in performing the necessary operations will also be significant, but not constant governing elements.

Another variable is the intensity of the approach lights which are subject to adjustment in steps based on the judgment of the Airport Controller. The lights must be at relatively low intensity under good visibility conditions and at relatively high intensity under very restricted visibility conditions. However, the high intensity may be a source of harmful glare or dazzle under certain conditions.

When a shallow fog causes the approach lights to be set at high intensity, the glare in the clear air above the fog hampers a safe transition from the approach light system to the runway light system because the pilot's eyes are adapted to the high background brightness produced by the glare, making it difficult to see the relatively less intense runway lights. These considerations show that the intensity of the approach lights should be actually governed on the basis of the slant visual ranges, runway light intensities and adaptation brightness levels applying to the pilot at his instantaneous positions during the approach and landing procedures. This illustrates how certain meteorological quantities should be observed, evaluated and forecast to secure optimum results with available visual aids.

Approach light systems have candlepower distributions in the form of a lobe. These systems are intended to aid pilots in maintaining flight on the ILS glide path, hence the peak intensity is projected so as to intersect the path at various points. However, this characteristic yields less effective guidance to pilots in aircraft with trajectories deviating from the glide path, that is, to those pilots subject to conditions which are adverse to a safe approach, and most need the aid in getting on the proper track.

The problem of providing additional guidance and intensity control under the adverse circumstances just outlined may be solved by those concerned with the design of approach light installations.

The solution of the problem of attaining the overall objectives outlined earlier thus may be seen from the foregoing analysis to involve the integration of a number of factors, most of them variable, lying in the province of many fields: physical, optical, engineering, environmental, meteorological, psychological and physiological.

V. ANDB - Weather Bureau - Sperry Gyroscope Company Projects

As steps in the attainment of some of the objectives, the Air Navigation Development Board has contracted with various organizations equipped to handle component parts of the problem. Among these organizations are the U. S. Weather Bureau and the Sperry Gyroscope Company.

The Weather Bureau is undertaking a number of developments and investigations to cover a period of three or more years with a view to better implementation of the attack on the problem from a meteorological stand-point. This project includes the development and testing of improved methods of observing visibility, ceiling, and other atmospheric conditions over the ranges that affect the problem.

The Sperry Gyroscope Company in cooperation with the Weather Bureau is undertaking a program of flight-landing operations under low ceiling-low visibility conditions in conjunction with intensive meteorological observations at the surface. Among the basic objectives in this project are the determination of the correlations between the ceiling and visibility data obtained at the surface and the vertical contact height* and the runway-threshold contact height**observed from the aircraft. Investigations of this character are important as steps in relating meteorological information to the conditions which the pilot actually experiences. At present the Sperry Gyroscope Company has a DC-3 Aircraft which will be employed for the project, with flights to be conducted at MacArthur Field, L.I., New York. This employment of only one type of aircraft is a limitation on the applicability of the results. In addition, MacArthur Field is at present equipped with a neon-bar approach light system extending for a distance of about 1700 feet ahead of the ILS runway threshold. This system does not provide peak or even average candlepower as great as is now yielded by modern high-intensity approach light systems which generally extend 3000 feet ahead of the runway threshold.

*"Vertical contact height" refers to the height of the aircraft at which visual reference with recognized objects on the surface is first established sufficient to permit visual determination of position, etc. (The recognized objects may be buildings, miscellaneous lights or approach lights, distinctive markings, surface texture or contrasts due to fields, roads, runways, bodies of water, etc.)

***"Threshold contact height" refers to the height of the aircraft at which is first established complete visual reference with the threshold of the runway.

Hence, the results based on the neon-bar system will not be wholly applicable to airports equipped with the high-intensity systems. The Sperry Company project will also be based on flights at a single airport, with a few highly experienced pilots.

VI. Extensions Deemed Necessary in Connection with Flight Project

In order to extend the degree of applicability of the results of the investigation, it would be desirable to include flights with larger modern aircraft types than the DC-3, and to have them conducted at two or more airports equipped with high-intensity approach light systems and the necessary meteorological devices for measuring low ceiling, low visibility and other quantities pertaining to the problem. Furthermore, it would be desirable to employ additional pilots with a view to determining the range of variability introduced by pilot differences. The work already contemplated under the Sperry Gyroscope Company-Weather Bureau project is of a continuing nature, and it would greatly enhance the end results of the effort if it were possible for several succeeding years to enlarge the scope by the addition of larger aircraft, better equipped airports for the flight investigations, and different experienced pilots. Means of securing these advances depends upon support received from other agencies and funds available for extension of the project.

VII. Present Measures Available for Attaining Increased Safety

Under Section IV., Analysis of the Problem, a number of factors were set forth as having an effect on the safety of landing operations. The aim is not only to increase the safety for the landing of any one aircraft, but also to reduce the number of missed approaches which create hazards for citizens on the ground and for occupants of aircraft.

First step after the analysis of the problem in attaining the objective is to study each factor into which the problem has been broken down and to attack part by part each one which provides an obstacle, reduces safety, or increases the relative frequency of missed approaches. The factors contributing most heavily to these ends receive a certain priority in this attack. Among the factors having a high priority are those which relate to the transmission of luminous energy from lights on the ground or from surface brightness contrasts to the air space in which the aircraft may be located during an approach. At the receiving end, for all points on the approach, landing and run course, the illumination from the lights impinging on the pilot's eyes and the apparent contrasts recognized by the pilot must be above certain threshold values depending on conditions. Thus, in large part the problem reduces to the difficult one of prediction of whether the illumination and the apparent brightness contrasts will exceed or be less than these threshold values at the time the pilot arrives at the various points on the approach-landing-run course under consideration.

At present, with use of high-intensity light systems and properly maintained painted runway stripes to give additional texture and guidance to pilots, much can be accomplished to increase landing safety and minimize missed approaches by pursuing the lines of attack described in the foregoing discussion.

VIII. Weather Bureau Plan of Attack on the Meteorological Aspects of the Problem

The Weather Bureau is applying a strong effort in conduction investigations and carrying out developments looking toward the objectives. Future programs are extensions of and new departures from the past programs. As advances are made the solution to the problem is seen to require the utilization of more complex apparatus and techniques than those currently employed

In general, equipment will have to be designed to yield observational data automatically, both locally as well as remotely, indicating and recording, continuously or at frequent intervals.

The contemplated projects, involving the development of equipment and techniques, may be outlined as follows:

(1) Range Transmissometers

Equipment to measure the horizontal transmissivity of the atmosphere near the surface over several ranges of baseline in two or more selected directions.

(2) High-Speed Ceilometers

Equipment to measure the cloud base height in relatively short cycles; calibration in standard terms based on flight experience.

(3) Slant Path Transmissometer

Equipment to measure the atmospheric transmissivity in slant paths up to several hundred feet altitude under low ceiling-low visibility conditions.

(4) Slant Visual Range Computer

Electronic and graphical devices to compute slant visual range, in part on the basis of the data secured from the slant-range transmissometer; calibration in standard terms based on flight experience. Note: Slant visual range is necessary to determine whether the pilot may accomplish the landing visually on descending below a certain critical altitude.

(5) Brightness and Illumination Meters

Equipment to measure the ratio of the brightness of the sky and ground, the background and the sky brightnesses, and the illumination falling on a horizontal surface, these data being involved in the determination of slant visual range.

(6) Cloud, Fog, and Precipitation Particle and Content Meters

Equipment to measure the particle sizes and water content of cloud, fog, or precipitation in so far as these are involved in the determination of horizontal visibility, ceiling, and slant visual range, within practicable limitations.

(7) Variability of Horizontal Visibility

Investigation of the space-time variability of low horizontal visibilities under different conditions and causes.

(8) Variability of Ceiling

Investigation of the space-time variability of low clouds under different conditions and causes.

(9) Variability of Slant Visual Range

Investigation of the space-time variability of slant visual range under different conditions and causes.

(10) Short-Range Forecasting

Development of improved techniques for short-range forecasting of horizontal visibility, ceiling, and slant visual range, taking account of the measurements and investigations referred to above.

Consideration should be given to certain additional, difficult requirements, which may be listed as follow:

(11) Contour Ceilometer

Development of apparatus which will yield a presentation of cloud-height contours (lines of equal height of lower boundary surface of clouds).

(12) Psychophysical Visual Measurements

Determination of threshold values of brightness contrast, illumination, etc., under practical field situations over a variety of conditions, which govern the detection and recognition of runways, runway lights, approach lights, and other objects. (Note: This is not strictly a meteorological project.)

It should be noted that many of the foregoing projects cut across the boundaries of a number of scientific disciplines, because the overall problem is extremely complex and entails numerous factors falling within the province of many fields. An effective attack on the problem calls for the coordinated efforts of workers in all of the fields concerned. The particular task of determining slant visual ranges in any selected inclined cone may be emphasized as being especially important, yet beset with extreme difficulties both of a theoretical and a practical nature when cloud, fog, or precipitation is involved.

It is believed that strenuous pursuit of the investigations proposed in the foregoing will lead to a satisfactory solution of most of the problems.

Discussion:

Col. Byrnes commented that in his opinion the project described by Mr. Harrison is of the greatest practical importance.

Mr. Middleton stated that he would like to congratulate Mr. Harrison on the scope and completeness of the project. Mr. Middleton stated that the big problem will be to get cooperation of all the people who could render assistance in the project. Mr. Middleton stated his hope that it would be possible for Dr. Duntley's equipment to be made available to Mr. Harrison's project for the measurement of the state of the atmosphere. Also Dr. Stewart's equipment for measuring slant visibility should most definitely be made available. Mr. Middleton suggested that Mr. Harrison contact Mr. Corwin about this. Mr. Middleton stated that in his opinion, it would be a million dollar mistake for Dr. Stewart's apparatus not to be made available to the project.

Dr. Duntley stated that he considered the project one of an emergency nature and agreed that everything possible should be done to assist it. Dr. Duntley stated however that he had mixed feelings about assisting with the project. The measurement of atmospheric attenuation is difficult under the best of circumstances. It is difficult to conceive how it can be done under the conditions of flight tests such as Mr. Harrison described. Dr. Duntley concluded that everything would be done which could be done to assist in Mr. Harrison's project.

Mr. Corwin assured Mr. Harrison that the Bureau of Aeronautics would cooperate in every way possible.

Dr. Hulburt commented that, is often the case, there is no dirth of money, ideas or equipment. The question is where can a man be found who can conduct the research.

SUMMARY OF THE REPORT OF THE
EXECUTIVE COUNCIL MEETING

Col. Byrnes stated that it might be worthwhile to remind those present of the mechanism by which military organizations request assistance from the Vision Committee. Assistance is requested through the military liaison officer of each of the three services. Funds for the Vision Committee are provided by the three services to make it possible for the Vision Committee to assist any organization who has a visual problem. The Vision Committee operates by setting up working groups which, in Col. Byrnes' opinion, have been very successful. These groups do not cost the services anything extra since the financial support for the Vision Committee is provided routinely.

Col. Byrnes stated that the Executive Council considered the present status of a number of working groups. A list of the working groups and problem areas which are under consideration by the Vision Committee follows:

A. Working Groups on:

Color Codes
Visibility at High Altitudes
Taxiway Lighting
Radar in Long-Range Bombers
Illumination and Dark Adaptation
Night Vision Testing
Color Filter Standardization
Reflection Optics
Searchlight Specifications

B. Problems of:

Optical Aids for Reconnaissance
A Manual for Clinical Acuity Charts
TAC Visual Reconnaissance
Optical Gunsights
Air Defense Radar
Visibility of Shells

Col. Byrnes reported that the budget is the same as in previous years. He stated that if anyone wishes to see how the money is spent, the budget is available for their perusal.

Col. Byrnes next reported that the Executive Council considered membership problems. Dr. Austin H. Riesen is to be invited to become an associate member of the Vision Committee.

Col. Byrnes reported that terms for two members of the Executive Council will end July 1, 1952. These members are Dr. Richard G. Scobee and Dr. Henry A. Imus. Dr. Imus is to remain a member of the Executive Council in his capacity as contract officer. The Executive Council has nominated a slate of four and the official members of the Vision Committee will be requested to vote by mail ballot to select two members of the Executive Council. The slate of four consists of Dr. Richard G. Scobee, Dr. Brian O'Brien, Dr. Glenn A. Fry and Dr. Benjamin J. Wolpaw.

Col. Byrnes then announced that Dr. Conrad Berens had been re-elected to the office of Deputy Chairman for two years and that he (Col. Byrnes) had been re-elected to the office of Chairman for two years.

Col. Byrnes reported that the next meeting of the Vision Committee is scheduled for November 21-22 at the Aero Medical Laboratory at Wright-Patterson Air Force Base. Scheduling of the meeting at the Aero Medical Laboratory is in accordance with the Vision Committee policy of having the fall meeting of the Committee at a military installation, and the spring meeting in Washington.

ABSTRACTS

359. Eye Fixations of Aircraft Pilots VI. Fixations During Day and Night ILAS Approaches Using an Experimental Instrument Panel Arrangement
Milton, John L., 1st Lt., USAF, McIntosh, Billy B., 1st Lt., USAF, Cole, Edward L., Major, USAF
AF Technical Report No. 6570
United States Air Force
Wright Air Development Center
Wright-Patterson Air Force Base, Dayton, Ohio
October 1951 (0)

"This report is the sixth in a series of investigations of eye movements of pilots during instrument flight. The frequency, duration and sequence of eye fixations made by 15 pilots when flying day and night ILAS approaches with a new panel arrangement are summarized. For purposes of comparison, data previously obtained with the standard Air Force panel arrangement during ILAS approaches under day conditions are included. All conditions investigated showed that the cross-pointer, directional gyro, gyro horizon and air speed indicator, are the most used instruments. Significantly more fixations and shorter fixations were made for day approaches than for night approaches. The total number of fixations and the average length of all fixations were approximately the same for both the standard and the new panels, although there were some significant differences between the individual instruments. More experienced pilots tended to make slightly more and shorter fixations than less experienced pilots. From the standpoint of the distance between the most frequent eye fixations, the new panel appears to have a better arrangement of instruments for ILAS approaches than the standard panel."

360. A Study of the visibility and Glare Ranges of Slope-line Approach Lights
Gilbert, Marcus S., and Pearson, H. J. Cory
Technical Development Report No. 150,
Civil Aeronautics Administration, Technical Development and Evaluation Center, Indianapolis, Indiana
November 1951 (0)

"This report includes a mathematical and graphical analysis of the visibility distribution of the slope-line approach-light system using the standard 250 PAR lamp. Some consideration also is given to the 400-watt, 115-volt lamp which is the standard of the U.S. Air Force. The analysis, based on Allard's Law, is made for the dual purpose of determining the distance from which a slope-line light can be seen by approaching pilots, and the distance from which it will appear to be excessively glaring to them, under a variety of daytime and nighttime visibility conditions and lamp brightness settings. These data are then used as a basis for a study of the angular settings of the lamps, and for a study of a possible modification in lamp sizes at the inner end of the system."

361. The Effect of a Simple Training Procedure on the Judgment of Visual Number
 Minturn, A. L., Reese, T. W., Kaufman, E. L.
 Technical Report SCD-131-1-1 Mount Holyoke College
 SCD Human Engineering Project 20-L-2
 September 1951 (0)

"The Problem - This report concerns the way in which people judge numbers of objects. The question "How many?" appears many times in daily life. A spotter may want to know how many ships are in a given area, or how many planes are flying overhead. In many practical situations there is no time to count these objects -- one must make a quick estimate. People generally make a lot of mistakes when they estimate quickly. Obviously, large errors in the judgment of number may have serious consequences in some situations. It would be an expensive mistake if a spotter called 20 planes 100, and equally expensive if he called 100 planes 20. Therefore, it is important to know whether a person's ability to judge number can be improved in some way.

"In this study, we asked whether estimating number could be improved by telling people how many objects there really were after they had made a judgment -- in other words, by correcting their judgments. Could subjects be trained by this simple procedure to judge number accurately and would this training be effective for any length of time?

"The Procedure - Thirty-five slides were projected one at a time on a screen for one-fifth of a second. On the slides were different numbers of black dots, ranging from 1 to 210. The slides were shown in a random order and subjects wrote down how many dots they thought they had seen. These written estimates were called the subjects' "reports". In the first section of the experiment, they were not told the correct number of dots after their judgment. In the next section of the experiment, they were told the actual number after they had judged. Eight months later, they judged the slides again without this correction.

"Ten students served as subjects. We calculated the error of judging each slide in the following manner. All the judgments made by all the subjects for any one slide were arranged in order and the middle or median reported number was found. This was subtracted from the actual number of dots on that slide. The result was then divided by the actual number to find percentage error for the group for that slide. This percentage error was positive or negative depending upon whether the subjects overestimated or underestimated the number of dots. Then a comparison was made between the percentage error before, during and after training.

"Conclusions

1. People do make more accurate judgments of number after training.
2. The effect of this training is almost immediate. Improvement is noticeable after very few corrections.
3. After eight months, judgments are still more accurate than before training though not as accurate as during training."

362. The speed and Accuracy of Discriminating Differences in Hue, Brilliance, Area and Shape
 Reed, J. B.
 Technical Report SDC-131-1-2, Mount Holyoke
 College, SDC Human Engineering, Proj. 20-L-2
 September 1951 (0)

"When we want to communicate with others, we discover that visual symbols are often more useful than words -- for example, the arrow indicating direction and the red light saying

"Stop!" A symbol can be read at a glance. Words giving the same information might take much longer to read. Under certain conditions, we might not be able to read words at all. Then too, we can organize symbols into codes which are then explained to our readers. Map making is an example of this coding process.

"Obviously, a visual code is useful only when one symbol can be distinguished from another. It is even more useful when the symbols can be distinguished accurately and quickly from each other. A code designer must give his symbols certain characteristics - size, shape, hue, and so forth - to help the reader discriminate them. These characteristics are called the discriminable aspects of the symbols. To work efficiently, the code designer should know what type of symbol is most effective. He should know which discriminable aspects to use.

"In the first experiment, therefore, we asked the question: which of the four common discriminable aspects of vision can people discriminate most rapidly and accurately--hue, shape, area or brilliance? (Brilliance is sometimes referred to as "value"). We attempted to solve a related problem in the second experiment. If people can discriminate a difference, say, in area, in a given time, exactly what effect would increasing or decreasing that difference have upon their speed? In other words, we wanted to know the functional relation between size of stimulus difference and speed of discrimination. We investigated this relation in two studies. In one, we used differences in hue, and in the other we used differences in area.

"We asked subjects to sort cards into a wooden box for both experiments. The box was divided into two compartments. In the first experiment, the subjects sorted a single pack containing sixty-four cards. One symbol was printed in the center of every card. There were two shapes, a triangle and a circle. Each shape appeared in two sizes; large and small; in two hues: red and green; and in two brilliance levels: light and dark. These hues, shapes, areas and brilliance levels were represented in all combinations in the pack. For example, there was a large light red triangle and a small light green triangle, etc. The subjects sorted the pack four times, once for each of the four aspects. The first time we might instruct them to separate all green symbols from all red symbols, disregarding any other way in which the symbols differed. The second time they would separate all the triangles from the circles, and so on.

"Fifty subjects were tested. We took the individual times and averaged them for each aspect. We then divided these averages by the number of cards in the pack. This gave us the average sorting time per card for the group. We did this separately for hue, area, shape and for brilliance. We also averaged the number of errors made in sorting for each aspect. These averages, when divided by the number of cards in the pack, give us the percentage error of sorting for the four aspects.

"Twenty-four of the subjects who participated in the first experiment also served in the second experiment. This experiment was divided into two sections. In the first section, we asked the subjects to sort five packs of cards for difference in area. There were 40 cards in each pack. Every card was printed with a single symbol as in the first experiment. The symbols were all black circles that differed only in area. There were two areas represented in every pack. The difference between these two areas, however, varied from pack to pack. For example, in one pack, the difference in area between the large and small circles was only 2.1 sq. mm. In another, it was as high as 14.4 sq. mm.

"We set up a parallel situation in the second section of the experiment. Here the subjects sorted six packs of forty cards for difference in hue. The cards contained circles that differed only in hue. Half of the circles in each pack were red, half were green. We varied the difference between the red and the green from pack to pack by changing the saturation of both hues. That is, we made the red more red and the green more green.

"As in the first experiment, the average sorting time for the group and the percentage error were calculated for each sorting.

"Conclusions

1. People can discriminate differences in hue and in shape faster and more accurately than differences in area or in brilliance.
2. On any visual display, therefore, the most important symbols should differ in hue or in shape.
3. As the difference between two areas or two hues is increased, discrimination time is decreased. After a while, increasing the difference between two hues or two areas has no effect on discrimination time. That is, this time gradually approaches a constant discrimination time for both aspects.
4. This constant discrimination time seems to be the same whether we are discriminating hue differences or shape differences. Therefore, we think that the time required to discriminate very large stimulus differences may be the same no matter what aspect we are looking at."

363. An Experimental Counterrotating Marker Beacon
 Pearson, H. J. Cory and Marcus S. Gilbert
 Civil Aeronautics Administration, Technical
 Development and Evaluation Center,
 Indianapolis, Indiana
 Tech. Dev. Report No. 160, Feb. 1952 (0)

"This report describes the development of a counterrotating marker beacon for use as a visual aid to airplane pilots in circling approaches. This beacon uses two projectors rotating in opposite directions to provide a pilot with an indication of his position with reference to the desired approach course.

"After construction and test of several models, a beacon which gives good directional indication on a circling approach was developed."

364. Development of a Retractable Slope-line Approach-light Unit
 Gilbert, Marcus S., and Pearson, H. J. Cory
 Technical Development Report No. 156
 Civil Aeronautics Administration, Technical
 Development and Evaluation Center, Indianapolis,
 Indiana
 January 1952 (0)

"This report discusses the development of a slope-line approach-light unit which, when not in use, will retract into a position on the ground, in order to reduce the possible hazard to aircraft taking off over the approach-light system. Two designs were completed, one for a hinged type and the other for a type that withdraws axially into a metal housing sunk into the ground. The hinged type was selected for fabrication and test as it offered a partial answer to the problem at a minimum cost of installation and minimum of maintenance and operating difficulties. The experimental model has operated satisfactorily in various kinds of weather during the period of 18 months in which it has been in use."

365. The Arrangement of Instruments, the Distance Between Instruments, and the Position of Instrument Pointers as Determinants of Performance in an Eye-Hand Coordination Task
 Fitts, Paul M., and Charles W. Simon
 AF Tech. Report No. 5832, Aero Medical Lab.,
 Contract No. W-33-038-ac-19816, E. O. No. 694-31
 Wright Air Development Center, USAF Wright-Patterson Air Force Base, Dayton, Ohio
 February 1952 (0)

"Three experiments are reported in which the effects of various visual stimulus patterns formed by different arrangements of instruments and pointers were studied. For the task employed, which was a continuous, dual-pursuit problem, the results of all three experiments are in agreement in indicating that subjects give significantly superior performance when

- a. instruments are close together,
- b. instruments are aligned horizontally,
- c. pointers are aligned at 9 o'clock for horizontally-separated instruments and at 12 o'clock for vertically-separated instruments, or else the pointers are counterpoised.

"The results of an extended learning study indicated that differences in the initial performance of individuals when using the different pointer-position patterns actually increased during fifteen daily practice sessions."

366. Modifications of the Slope Line Approach Light System
 Pearson, H. J. Cory
 CAA Technical Dev. and Evaluation Center
 Indianapolis, Indiana. Technical Dev. Report
 No. 167 April 1952 8 pp. (0)

"This report describes the results of certain modifications in the design and arrangement of the basic slope line approach light system. These modifications include changes in horizontal and vertical settings of the lamps, changes in lamp wattage, the addition of horizontal bars, and changes in the threshold light pattern. The purpose was to improve lateral coverage, to provide more effective lead-in guidance, to reduce glare, to improve roll guidance and threshold marking, and to provide distance marking.

"Service testing demonstrates that effective distance marking is provided, and that material improvement is achieved in lateral coverage, lead-in guidance, roll guidance, and threshold marking. Reduction in glare is indicated but not yet proved."

367. Fixations During Zero-Reader Approaches in a Jet Aircraft
 Milton, John L., Capt., USAF and Major Fred J. Wolfe, USAF
 Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio
 WADC Tech. Rep. 52-17, Feb. 1952 15 pp. (0)

"This report covers one of a series of investigations of eye movements of pilots during instrument flight. The frequency, duration, and sequence of eye fixations made by 10 pilots

during Zero Reader approaches under simulated instrument conditions are summarized. Comparisons are made between results obtained on Zero Reader approaches and results obtained on ILAS approaches using a somewhat similar instrument panel arrangement.

"During Zero Reader approaches the Zero Reader Instrument, the Air Speed and the Gyro Horizon are the most used instruments. The Zero Reader, which includes directional gyro information and cross-pointer information, receives the same amount of attention during Zero Reader approaches as the Directional Gyro and Cross-pointer receive during ILAS approaches. The optimal arrangement of the instrument panel for Zero Reader Approaches (using frequency and length of eye movements as the Criteria) would call for location of the Zero Reader in the top center position with the Gyro Horizon and Air Speed located adjacent and horizontal."

368. Blinking During Visual Tracking

Poulton, E. C. and R. L. Gregory
 Medical Research Council A.P.U. 152/51
 Medical Research Council, Applied Psych.
 Research Unit, The Psychological Lab., Cambridge
 June 1951 15 pp. (0)

"In order to determine the incidence of blinks during visual tracking, their effect, and the nature of this effect, two experimental arrangements were used. In one the subject had to keep a pen upon a moving line, his blinks being recorded without his explicit knowledge both electronically and by two observers. In the second he had to keep two pointers in line using a positional control, the display being occluded intermittently in one part by a wheel tachistoscope, in another by his own voluntary blinks.

"It was found that the blink rate was raised when the subject expected the tracking to start, and again after tracking. During tracking, it was reduced, particularly initially. The blinks that did occur tended to be concentrated in the easy periods of the course. It was not possible to predict the individual's blink rate while tracking from a knowledge of his true "resting" blink rate.

"Blinks were most detrimental when the course was difficult, especially when anticipation was not possible. This effect was due at least partly to interference with vision. But temporary inattention had to be postulated to account for the delayed deterioration following blinking.

"It was suggested that the blink rate might serve as an index of attention. Blinking cannot be excluded as a cause of accidents. Inattention, of which blinking may be the earliest sign, is probably far more important in this respect."

